Modeling, Analyzing, and Visualizing Human Space Appropriation

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PREFACE

This work would not have been possible without the help of many people.

I would like to express my thanks to all colleagues at the Department of Geography at the University of Zurich, who gave me a warm welcome three years ago and since then have provided an excellent, helpful, and intellectually stimulating research environment.

In particular, I would like to thank Prof. Dr. Sara Fabrikant for all the valuable feedback, Dr. Corinna Heye for the assistance with statistical software and methods, and last but not least my supervisor Prof. Dr. Sabine Timpf for all the input, discussions, and encouragement.

I would like to express my gratitude to the Swiss National Science Foundation that funded the research project.

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SUMMARY

Urban public parks play an important role for the well-being of the citizens. They offer the possibility to participate in public life independently of socio-economic group, age or ethnicity, and can thereby improve the quality of life for urban citizens and foster social sustainability. While a socially sustainable space appropriation reflects urban diversity and strengthens integration and participation, processes of exclusion and domination by park visitor groups can produce persisting conflicts. Small urban parks with a potentially high diversity of activities and heterogeneous visitor groups are especially important and vulnerable at the same time.

The aim of the research is the development of a quantitative representation of individual human space appropriation in order to model the space use and appropriation in public parks. Although research in environmental psychology and anthropology has produced theories on individual human spatial behavior, no model exists so far that represents the interactions between several individuals and their appropriation of space.

Therefore, it proved necessary to develop an original methodology for the representation, modeling, and analysis of human space appropriation. The model conceptualizes space appropriation by park visitors as the process to achieve a desired level of privacy to carry out their intended activities. It consists of an active component that is mainly determined by the type of activity pursued, and a passive component that builds on the concept of personal spaces in which one would like to remain undisturbed. If these active and passive components overlap between individuals, the potential for crowding, stimulus overload, and possibly even conflict or displacement exists. In order to ground the model in reality and to learn more about actual space use and appropriation, the research was embedded in a case study. Extensive observations with a newly developed method provided data about the usage of three small urban public parks in Zurich, Switzerland.

The model was implemented and the recorded data was analyzed with several spatial analysis methods, including qualitative and quantitative, as well as object-based and field-based methods. The actual, observed park usage has been analyzed with several spatial statistic methods. Finally, the visualizations were evaluated using a simple framework based on the level of interactivity and complexity, suggesting specific visualizations for practitioners and researchers.

The key findings are that the object-based approach’s crisp boundaries and spatially uniform values suggest a homogeneity and clarity that does not reflect actual space appropriation. In contrast, even a relatively simple field-based implementation with symmetric kernel density estimations satisfies the two key requirements: First, a non-linear, smooth distance decay of space appropriation intensity. Second, the representation of uncertainty, i.e. the inherent inaccuracy, incompleteness, and vagueness. Concerning actual appropriation patterns, static activities are the most frequent, while dynamic activities occur rather at the periphery of the parks. Although male and female visitors do not cluster within the parks, the male visitors dominate dynamic activities. Younger and older park visitors rely on a park’s infrastructure, while adults dominate the open spaces. During the late afternoon and early evening, the number of female and young visitors decreases. In all parks, the gender structure of the observation sample is not significantly different from the neighborhood population. This is in contrast to the age structure, which differs significantly from the neighborhood population with fewer seniors and more children. There is very little direct interaction between groups of visitors, neither positive nor negative. The observations and analysis found no indication of general intra-site displacement processes. Clearly, each user group seems to have certain preferences with regard to the park infrastructure. Therefore, a diverse but carefully arranged infrastructure gives heterogeneous user groups the possibility to participate.

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Part I: Introduction

1 The Research Agenda

The overall research objective of this work is to improve our knowledge about people's use and appropriation of public space. More specifically, it is my aim to develop a model for the quantitative representation of individual human space appropriation. Using this model, I will be able to acquire information on intensity and variability of individual human park use and space appropriation at the micro scale.

During the course of this work, I have developed such an original model of human space appropriation, collected new empirical data from observations in three public parks, and subsequently analyzed and visualized this spatio-temporal data in multiple ways, including two implementations of the aforementioned model.

This introductory chapter's priority is to give the reader a first overview of "Modeling, Analyzing, and Visualizing Human Space Appropriation". The first section explains the motivations behind the research project and its context. Then, the reader will learn more about the thesis' scope and setup, followed in the third section by a description of the key research objectives this thesis addresses. In the final forth section, I briefly present the structure of the thesis.

1.1 Urban Public Parks – Challenges and Opportunities

I use the term "public park" as shorthand for "small urban public park". A public park is generally conceived as a public green space oriented towards recreation and public access rather than an area preserved for its natural features (Forsyth and Musacchio 2005). Surveys have shown that citizens consider urban parks to be an important element for their well-being, even if used only occasionally (Solecki and Welch 1995; Thompson 2002; Tinsley and Croskeys 2002; Chiesura 2004; Krenichyn 2004; GrünStadtZürich 2006; StadtZürich 2006). Public parks in general offer great potential to raise the quality of life for urban citizens: They provide social and psychological services that are of crucial significance for the well being of the urban population (Chiesura 2004), and can be embedded in daily routines if easily accessible (Forsyth and Musacchio 2005). They are also places where urban citizens can learn important values such as coexistence, cooperation, and tolerance through participation (Low, Taplin et al. 2005) by experiencing and living cultural diversity (Garcia-Ramon, Ortiz et al. 2004). Public authorities have widely acknowledged that urban public parks are therefore key land uses in nowadays' growing cities. Subsequently, they spend considerable amounts of money on designing, building and maintaining them (Forsyth and Musacchio 2005).

Two processes oppose the positive effects of public parks on citizens' quality of life: The ongoing urbanization increases the scarcity of opportunities for outdoor recreational activities, thereby increasing the strategic importance of urban public parks even more (Manning and Valliere 2001; Chiesura 2004). Another threat is to the general accessibility of urban public parks, since there is an increase in "patterns of design and management that exclude some people and reduce social and cultural diversity" (Low, Taplin et al. 2005). In addition, many parks still cater for the activity types of single white men (Forsyth and Musacchio 2005). A more pluralistic ideal would not expect conformity, but would strive to accept a diversity in needs, attitudes and expressions (Thompson 2002).

There is still little detailed information available about the usage patterns of public parks. Perhaps this is due to the necessary technology for automatic visitor monitoring still being under development (Arnberger, Brandenburg et al. 2006). Park usage studies have been mostly in the form of off-site surveys, neglecting direct observations to find out more about how parks are actually used (GrünStadtZürich 2005; Zürich 2005; Fischer, Stamm et al. 2006). Only two studies have explicitly collected information through direct observations and mapped a spatial distribution of visitors, albeit in an aggregated manner (Baur, Zemp et al. 2000; Paravicini 2002). Another study used simple spatial analysis methods for the computation of crowding and carrying capacity, although with limited theoretical foundations (Gedikli and Özbilen 2004).

Although public parks are in principle accessible by everyone and conflicts should be resolved ideally by compromise, the two informal but significant processes of displacement and exclusion can oppose equal participation and endanger social sustainability (Owens 1985; Manning and Valliere 2001; Paravicini 2002; Thompson 2002; Brandenburg, Arnberger et al. 2006; GrünStadtZürich 2006). Displacement occurs if an individual park user (or a group), through his or her behavior, discourages or inhibits others from using the park as they intend to, causing them to relocate within the same park or to move to another park. A (potential) user group is excluded from a park if they do not visit it at all, despite expressing the motivation to do so or having been observed in other parks (Ostermann and Timpf 2007). In this respect, parks can mirror conflicts observed in our increasingly heterogeneous societies (Low, Taplin et al. 2005). These conflicts can be issues of gender, age, ethnicity, or religion. Conflicts play an ambivalent role: On the one hand, they can lead to increased interaction and thereby greater integration of different socio-economic milieus. On the other hand, they can be the first step to an exclusion of specific socio-economic groups, and a subsequent exclusion of them from everyday life and participation if an arrangement is not reached.

The following pictures show very different scenes of park use. While the first image (Figure 1-1) shows a relatively well-frequented park with visitors pursuing diverse activities, the other photograph (Figure 1-2) shows an almost deserted park.

Figure 1-1: Intensive Use of Park Space

Source: The author; Zürich, 17.08.2006

Figure 1-2: Extensive Use of Park Space

Source: The author; Zürich, 17.06.2006

Managing diversity, so that cultural and social heterogeneity becomes a driving force of social sustainability and not an impediment to it, is presently one of the greatest challenges for public authorities (Stren and Polèse 2000). This challenge is even greater for small parks in urban areas (Forsyth and Musacchio 2005). In order to identify elements of design and planning as well as strategies of management that foster a socially sustainable appropriation of public parks by the urban citizens, one needs to find out more about the usage and appropriation of small urban public parks.

1.2 Setup and Scope of the Research Project

The preceding section has already hinted at the fact, that this is a crosscutting research project[1], which overlaps with many disciplines. This interdisciplinary character is one of the main strengths, while at the same time it poses the risk of insufficient focus for an in-depth treatment of the subject. In order to focus this work, I will first try to outline the scope of the thesis and position it in the research context.

Many research activities focus on either qualitative or quantitative methods. Social sciences such as anthropology or sociology have focused on people but neglected space. Often, spatial analysis is limited to a visual analysis of the mapped results. Quantitative geographic research has done the opposite in its search for universally applicable laws, and frequently overemphasized space in a determinist manner. Reproduction of the natural and social world was reduced to technical problems, where errors are the result of lack of technical skill or unintentional distortion (Pickles 1994). Consequently, quantitative geography is still strongly associated with positivist epistemology (Sheppard 2001; Poon 2005). For those advocating non-positivist knowledge production, qualitative methods have become an accepted strategy (Sheppard 2001; Pavlovskaya 2006). However, this criticism ignores the more recent developments in quantitative research, namely an acknowledgement of the importance of local variations and the limits of situated geographic knowledge (Duckham and Sharp 2005). There is a clear trend from the "global" to the "local" (Fotheringham, Brunsdon et al. 2000).

This research intends to contribute to closing the gap between mainly qualitative social sciences and mainly quantitative spatial analysis. This study employs a pragmatist, mixed

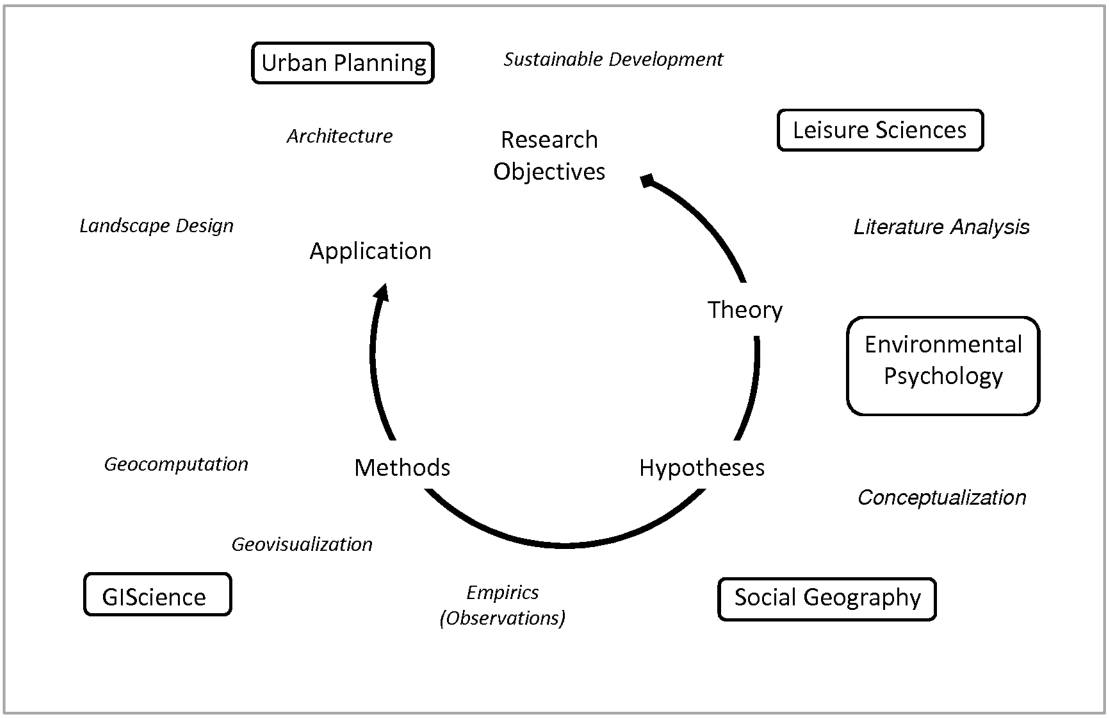
1 This thesis has been funded by the Swiss National Research Program No. 54 "Sustainable Development of the Built Environment" and was part of the research project "Sustainable Design, Management and Appropriation of Urban Public Parks" (Applicants: Dr. Elisabeth Bühler, Prof. Dr. Sabine Timpf; www.geo.uzh.ch/nfp54")

methods approach, using both qualitative and quantitative methods sequentially and iteratively where appropriate (Creswell 2003; Morgan 2007). Further, I propose a simple yet efficient model to capture and represent the complex interpersonal processes of human space use and appropriation at the micro level. This model implements concepts from anthropology and environmental psychology, such as the social agitation framework (Kuentzel and Heberlein 1992) and proxemics (Hall 1966). Its main components are socially constructed spaces of interpersonal distances and activity spaces. Approaches from behavioral geography also focus on cognitive and decision-making aspects of human spatial behavior (Golledge and Stimson 1997). However, they address mainly the meso- and macro-scale, i.e. when and why people would visit parks, and therefore are not of immediate relevance to this work. Another important aspect of this thesis is the empirical foundation for the modeling and analysis. In order to collect data, three public parks were observed over the span of three years for a total of almost 150 hours. The park visitors and their activities were recorded into a database, providing the basis for the analysis and modeling. Subsequently, I employed established spatial analysis methods in new ways to analyze the spatial-temporal distribution of park visitors. The intensity of space use, potentially crowding situations and resulting conflicts between park visitors can be modeled using information about the environment, the activities of the park users and individual characteristics such as age and gender. Several visualization techniques are employed throughout the research process to explore the data, to generate hypotheses, and to communicate the results.

Concerning the meaning of the term “space appropriation”, I acknowledge that in the context of sociology and social geography, the term “space appropriation” is used primarily in an aspatial sense, while at the same time involving more symbolical and contextual information.

In summary, the target dimensions and goals of the research project are situated in the context of urban planning. Its theoretical background and concepts are taken from environmental psychology, leisure sciences, and social geography. Finally, its methods are situated in the context of social sciences and geographic information science. The following Figure 1-3 shows the elements of the research project and the general workflow. The thesis focuses on the aspects of theory and hypothesis generation, modeling as well as methods and analysis, while the research objectives and the application of the results are part of the overall research project.

Figure 1-3: Scientific Context and Components of the Project



Source: own design

The contributions to the scientific community are:

- The development of a new methodological and conceptual framework (for the analysis and visualization of human space appropriation)
- A cross-disciplinary approach to a specific problem (geographical information science, computer science, information visualization, psychology, cognitive sciences, sociology, urban planning)
- New extensive data collection (observations)
- The application of existing spatial analysis techniques to a new research domain (quantitative spatial analysis to individual social interaction)

The next section presents the objectives in detail.

1.3 Research Questions

The interdisciplinary character of this research project leads to large number of research questions. Since it was not possible to treat them all with due time and space, a careful selection had to be made.

The research project’s motivation was primarily to learn more about possible processes of exclusion or domination, which rule out a socially sustainable park appropriation by the urban citizens. In order to identify such processes, more knowledge about the process of space appropriation itself, as well as quantified and representative information on intensity and variability of individual and aggregated park use is required.

This thesis reflects and expands the research project's original motivation: Of central interest are the development of a quantitative representation of space appropriation in general, and the analysis of newly collected empirical data of park use in order to identify potential crowding, conflicting interests, potential and actual conflicts, and resulting processes of exclusion and displacement.

As a result, the three main research questions that guided this work are:

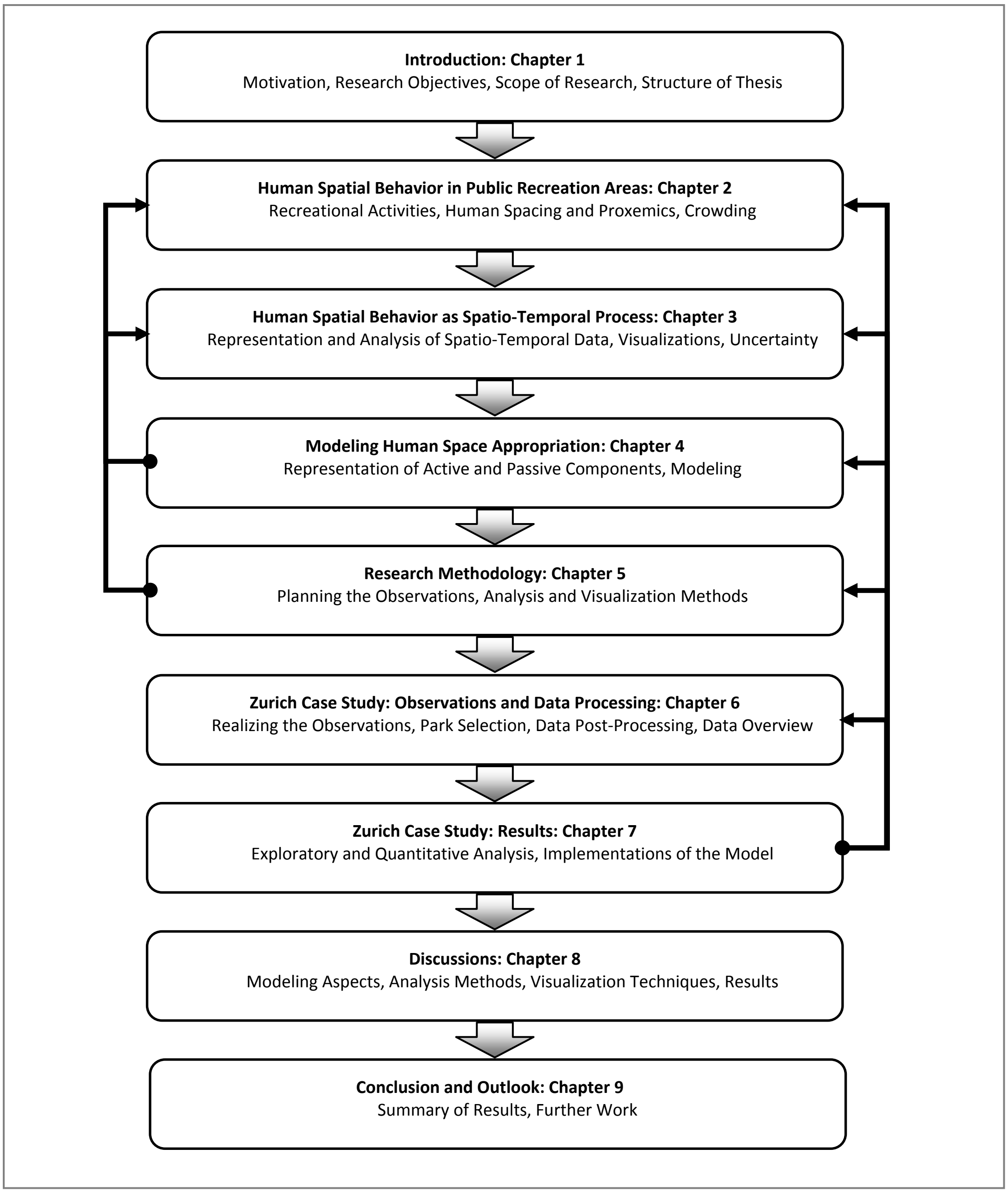
1. What model could represent the spatio-temporal properties of space appropriation and potential crowding?
2. Which methods are suitable for implementing the model of space appropriation, analyzing the observation data, and visualizing the results?
3. What is the spatio-temporal distribution of observed park visitors, and do the resulting patterns of space appropriation indicate processes of exclusion and domination?

From this list of research questions, it is clear that the thesis focuses on methodological questions as well as on applied research. In summary, the key research objective of this thesis is to develop a methodology for the analysis of space appropriation in public parks and in doing so provide the means for making informed planning decisions.

1.4 Thesis Structure

The thesis follows the general workflow of the research and the established tenets of publications. After this Introduction (Chapter 1), Part II introduces the relevant theoretical background on both individual human spatial behavior (Chapter 2) and spatio-temporal data (Chapter 3). Part III develops the conceptual framework and model (Chapter 4), and presents the applied methods (Chapter 5). Chapters 4 and 5 also address the first and second research question, respectively. In Part IV, the actual empirical work (Chapter 6) and analysis results (Chapter 7) are described, addressing the second and third research questions. The last Part V focuses on the discussion of the analysis, the visualization techniques and the results obtained (Chapter 8). The thesis concludes with some answers and proposition for further work (Chapter 9). The following Figure 1-4 shows the workflow, including the feedback to previous Chapters.

Figure 1-4: Research Workflow and Structure of Thesis



Source: own design

PART II: THEORY & STATE OF THE ART

2 Human Spatial Behavior in Public Recreation Areas

The aim of this Chapter is an introduction to the relevant theories of human spatial behavior at the micro scale (both spatial and temporal), and to the way people participate in leisure activities. From these two sources, I develop in Chapter 4 a model of human space use and appropriation that allows a quantification and subsequent analysis with spatial analysis tools.

2.1 Individual Human Space Use and Appropriation

This research is about human spatial behavior, which has been a focus in human geographic studies for over a century. Consequently, a large body of work exists. Here, only those aspects are introduced which are of particular interest for this work, i.e. individual human use and appropriation of space at the micro-scale.

2.1.1 *Geographical Concepts of Space*

Theorizing about space has been central to human geography. Today, it is widely acknowledged that the physical world is symbolically structured by the social world and society (Werlen 1993; Löw 2001), and inseparable from social processes and relations (Pavlovskaya 2006). However, quantitative spatial research has overemphasized space in an absolute, determinist, and functionalist manner. It continued to regard space as a container in which geographic phenomena are located. Thus, research in geography has focused primarily on physical space for a long time, and neglected individual use of space. Conventional GIS perpetuates this concept of absolute space as a container of objects with a finite extent and precise location. Only recently have new approaches tried to adopt a people-based stance, in which space is not a container that determines human action, but also something, that is produced in turn by human action (Hägerstrand 1970; Werlen 1993; Golledge and Stimson 1997; Werlen 2000; Miller 2005).

In this research project, I generally follow a constructivist understanding of space: Space is neither absolute nor a container in which social phenomena or people are placed and in which they interact. Instead, spaces are a relational ordering of bodies such as material infrastructure and people. Public spaces like urban parks are institutionalized spaces that are structured by the material resources and social rules. These relational spaces, produced and maintained through the actions of people, are dynamic and always in the making. In the case of public parks, this means that planners, designers, and users of the parks construct different spaces. Two processes determine the construction of a user's space: Synthesis and Spacing (Löw 2001). Synthesis means the mental construction of the surrounding space by synthesizing the perceptions of the material infrastructure and other park users with the individual experiences, memories, and preferences. The result of the synthesis process influences the spacing, i.e. where the new park visitors spaces him- or herself in relation to the other objects and visitors, thereby modifying the other users' space. This reciprocal relationship between action and space is the duality of space (Giddens 1988; Löw 2001).

2.1.2 *Peoples' Use and Appropriation of Space*

Actual appropriation of space by people has been researched mainly in the social sciences, especially anthropology, environmental psychology, and sociology (Hall 1966; Goffman 1974; Altman 1975; Freedman 1975; Baldassare 1978; Johnson 1987; Schoggen 1989; Veitch and Arkkelin 1989; Bourdieu 1991; Löw 2001).

At this point, it is necessary to define further my understanding of the terms "space use" and "space appropriation". I understand space use as measurable through direct observations. However, it is still fraught with many types of uncertainty, including the categorization used by the observers, the boundaries of activities, and others (compare Chapters 4 and 5). Space appropriation, in contrast, is a process that cannot be observed directly and is thus only inferable indirectly from the observations by employing a conceptual model. Space appropriation is a process in which each and everyone constantly, sometimes consciously and sometimes unconsciously, claims the surrounding space. On the one hand, this happens for space that one considers his or her personal space, into which intrusion by others can be considered as improper. On the other hand, space is also appropriated by actively positioning one's physical body and carrying out some activity. Clearly, this process can lead to conflict between competing or incompatible appropriations of space. In the private space of personal housing, such conflicts occur within social groups of familiar people, such as families or friends. In the public sphere of urban parks, the appropriation and use of spaces are a constant negotiation with strangers.

2.1.3 *Personal Space and Proxemics*

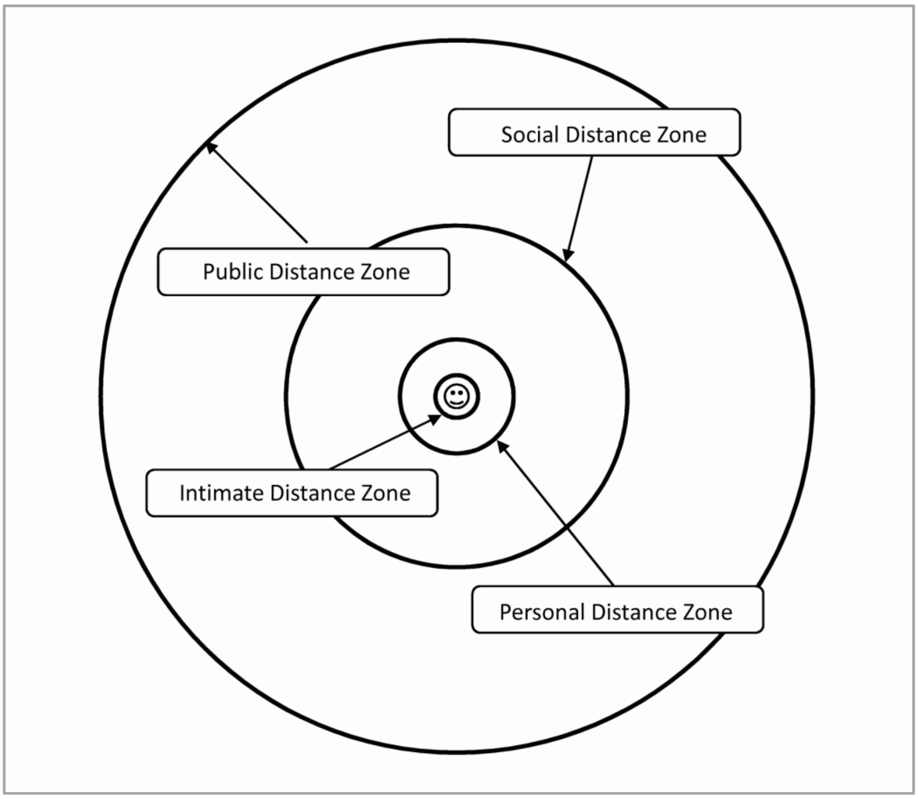
The concept of personal spaces forms part of the theory of proxemics as developed by Hall (1966). Proxemics describes a number of measurable, generally preferred distances that are used for the interaction between people. Based on hundreds of interviews and observations, Hall formulated the theory that the preferred distance for communication between people is reliably correlated with their social distance. The theory of proxemics was subsequently expanded by the introduction of distinct types of space. While fixed-feature and semifixed-feature space would represent the effect of a park's infrastructure, the informal personal space influences the interaction between people. This interaction can be further described by several behavior categories, such as posture or sociopetal-sociofugal axis (facing). Since this thesis focuses on interpersonal distances, they are described in more detail in the following paragraphs.

Hall (1966) conceptualizes personal space as a succession of four concentric spheres with a person at their core. The four distance zones are:

- Intimate distance zone: It covers the range up to 45 cm (18 inches). It is used for embracing, touching, and whispering. The field of vision is small, but very fine details can be discerned. Olfactory sensory impressions play an important role.
- Personal distance zone: It ranges from 45 cm up to 120 cm (4 feet), and is mainly used for the interactions among good friends. While the olfactory senses are reduced in importance, another person can be viewed completely, thus allowing detailed information about body language (posture, etc.).
- Social distance zone: It ranges from 120 cm up to 3.6 m (12 feet), and is used for interactions among acquaintances and formal interactions. Interestingly, the close distance approximates the distance where two persons interacting can barely touch one another with outstretched arms (keeping someone at arm's length!).
- Public distance zone: Ranging from 3.6 m up to 7.5 m (or 25 feet), it is reserved for public appearances and speeches. Most important are speech and body language, while facial expressions become indiscernible.

According to Hall, the posture and body spacing – compare the production of spaces (Löw 2001) – are mostly unintentional reactions to sensory inputs which can be very subtle. These sensory inputs mainly concern the potentially possible communication cues, some of which have been listed above. Unwanted, inappropriate intrusion into these spaces by others can lead to anxiety or discomfort, depending on the relationship or hierarchy between the individuals. The following Figure 2-1 shows the distance zones as proposed by Hall.

Figure 2-1: Personal Distance Zones



Source: own design based on Hall

As argued by Altman (1975) and Baxter (1970), these interpersonal distance zones also vary with age, gender, and ethnicity, with the latter having the greatest influence. The main difference is for Latin or Arabic cultures to communicate with acquaintances (usually social distance) at the personal distance (in European and Anglo-American cultures reserved for good friends), and more frequent body contact. Other researchers have expanded the basic concepts to include factors for nonverbal communication such as posture, and distinct levels of sensory input (Littlejohn and Foss 2005).

I challenge this rather static picture and propose to change the shape of the personal spaces according to the type of activity, speed of movement, and interaction mode. For the beginning, in order to reduce the number of factors, the focus is on their relevance for activities. The incorporation other aspects, such as modifying shape and size of personal spaces according to activity or individual characteristics, or the operationalization of the fixed-feature space and facing, will be a future goal.

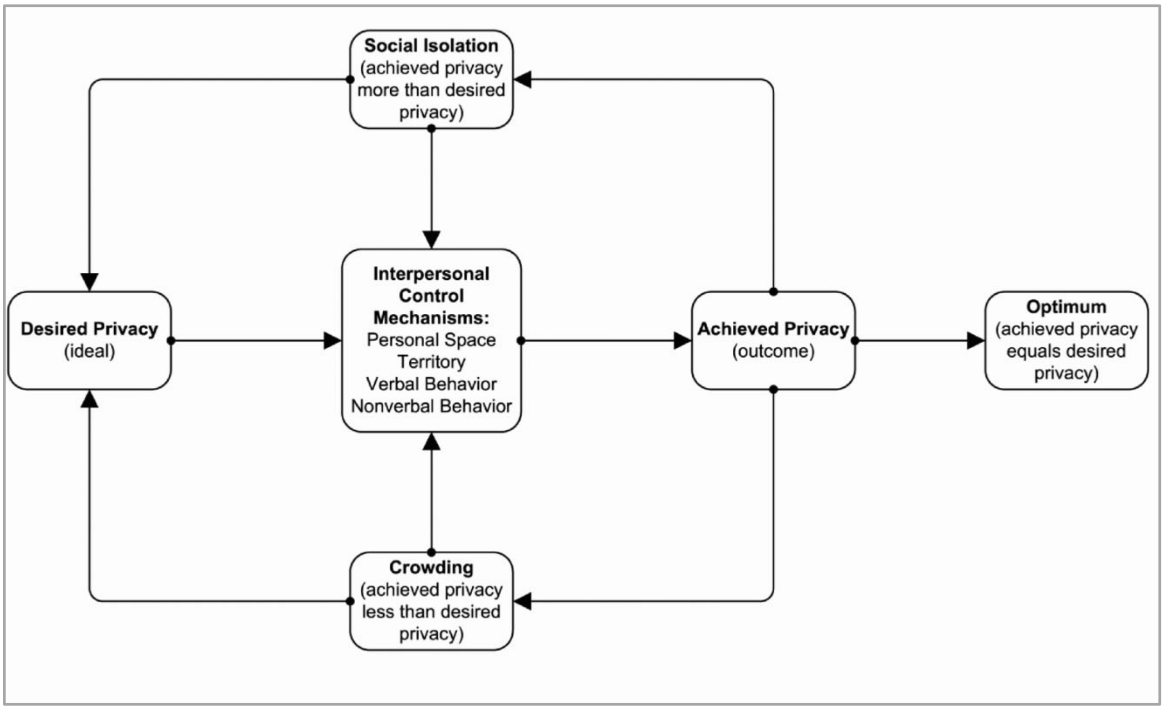
2.2 Leisure Activities, Crowding and Conflict

Crowding has been addressed comprehensively in the research literature on recreation and leisure activities. I will not give an exhaustive overview of this large body of research, but instead highlight the relevant aspects and publications.

2.2.1 *Visitor Density and Perceived Crowding*

First, it is important to make a distinction between simple visitor density and perceived crowding. Generally, crowding is regarded as a negative experience associated with high density. While it would be possible to use an arbitrary density value as a threshold value for a crowded situation, this would not reflect the psychological effects of crowding. Freedman (1975) argued that high population density does not automatically lead to dissatisfaction, but aggravates already existing positive or negative emotions, a view supported by others (Altman 1975). The following Figure 2-2 shows the relationship between privacy, crowding and isolation:

Figure 2-2: Privacy, Crowding and Isolation



Source: Altman (1975)

As seen above, Altman describes four principal methods for regulating the achieved privacy, calling them interpersonal control mechanisms:

1. Verbal Behavior represents actual confrontation though not necessarily aggressiveness, rather meaning attempts to solve a conflict by debate and discourse.
2. Non-Verbal Behavior includes all responses not covered by the other mechanisms, such as change of facing, use of visual blinds, etc.
3. Territory means the establishment of boundaries in order to claim a specific area. The boundaries can be constructed using materials that actually pose a hindrance, such improvised fences, or simply a towel.
4. Personal Spaces as a mechanism of interpersonal spacing (Löw 2001).

A review of the literature and preliminary observations indicated that personal spaces are the most important control mechanism in an urban public park setting. Instead of engaging in (non-)verbal exchange or claiming a delimited territory, maintaining a certain distance to a nuisance or intrusion is much more common. Using a territory is also a conscious act, while personal spacing is an unconscious act that always influences human spatial behavior.

Crowding therefore is not purely a question of density alone, but also dependent on the expected and needed use levels of activities, the context of the setting, and finally on subjective expectations and norms. Research has indeed found consistently low correlations between perceived crowding and overall satisfaction of the visitors with the recreational experience (Kuentzel and Heberlein 1992).

In the literature, there are two main approaches to describe the effects of crowding. First, a social agitation framework developed by Gramann (1982) relies on sociological principles and highlights factors such as stimulus overload and social interference. Stimulus overload refers to negative effects when one’s behavioral options are reduced and a reduction of stimuli through adaptive behavior is not possible. Social interference can be understood as behavior or presence of others interfering with the attainment of an important goal or activity (“goal-blocking”). Stimulus overload and social interference occur when the social carrying capacity of a recreation area is exceeded. The resulting adaptive behavior is reduced interaction and substitution or exclusion (Evans 1978; Baum and Paulus 1991). This approach shares similarities with the earlier conceptualization of crowding proposed by Altman (1975). Second, a normative approach as suggested by the work of Shelby and Heberlein (1986) focuses on cognitive elements that constitute crowding. The subjective character of crowding complicates the development of threshold values and general norms. Manning et al. (1999) give an overview on the research of developing norms for crowding and present their own results. Measuring those norms proved very difficult and results differed according to type of measurement procedure. Arnberger (2005) found in an empirical study that the tolerance level for social carrying capacities depends largely on the type of activity.

In summary, I understand crowding as a negative environmental effect that causes a subjective state of stress through stimulus overload and social interference. Several possible coping mechanisms exist that will be discussed in detail in the next section.

Another important distinction is that between crowding and actual conflict or confrontation: Owens (1985) attempts to define recreational conflicts as a negative experience that occurs when individuals or groups compete for shared resources (such as space), and this competition prevents at least one of the participating groups or individuals from benefiting. In this respect, conflict is frequently understood in a similar manner as crowding, i.e. as a result of exceeded social carrying capacity and subsequent stimulus overload and social interference among users (Manning 1999). However, Owens argues that conflict, once established, remains an enduring psychological state that is not limited to a current visit to the recreational site and its currently crowded situation. Instead, it alters expectations for future visits and can thereby influence future experiences in a negative way. Marcoullier, Scott et al. (undated) see conflict as one element in a wider range of interactions between recreational users and their activities. They introduce four basic categories of interaction among activities: Complementary (no conflict), Supplementary (minor conflict when some threshold point is reached), Competitive (conflict), and Antagonistic (strong conflict). Citing several case studies, they also argue that conflicts in recreational uses are very often asymmetrical in nature, e.g. bird watchers may experience significant (antagonistic) goal interference from all-terrain vehicle users, while the latter view bird watchers as supplemental in their activity.

Literature shows that conflicts are also influenced by ethnicity, which may be attributed to differences in social values (Marcouiller, Scott et al. undated). I argue that conflicts are rather a result of conflicting activities than ethnicity, which is the dependant variable: This view is supported by some researchers (Payne, Mowen et al. 2002; Tinsley and Croskeys 2002; Ho, Sasidharan et al. 2005; Low, Taplin et al. 2005), who note that certain ethnicities seem to prefer specific types of recreational activities.

2.2.2 *Strategies for Coping with Crowding and Conflict*

As mentioned in the preceding section, visitor satisfaction frequently remains at high levels despite high-density situations. Research has shown that visitors employ several strategies to cope with a perceived crowding situation. The two theoretical approaches to crowding (see above) also emphasize different coping mechanisms (Kuentzel and Heberlein 1992). The social agitation framework focuses on the behavioral origins of crowding respective coping mechanisms. These include:

- Encounter avoidance or reduced interaction with present encounters
- Intrasite displacement to an alternate location within the same site
- Intersite displacement to an altogether different site.

Coping mechanisms that the social norms framework focuses on are:

- Site succession refers to the expected and changing (adapting) use levels of sites
- Product Shift involves a re-labeling of the whole recreational experience
- Dissonance reduction employs several strategies to reduce the tension between expected and experienced recreation.

Manning and Valliere (2001) report a pervasive use of both behavioral and cognitive coping mechanisms in outdoor recreation. Kuentzel and Heberlein (1992) propose a hierarchy of these coping mechanisms, because “changing one’s mind seems an easier and more specific form of adjustment than altering one’s trip”. Nevertheless, they did not find conclusive evidence in their study to support this hypothesis. Instead, both behavioral and cognitive coping mechanisms were employed, although not in the same frequency: The results did not support the inter-site displacement theory, but there was evidence to support intra-site displacement as an employed behavioral coping mechanism. This adaptive behavior would be observable in the appropriation of space by park visitors. Chapter 4 will show how this information can be used in a model of human recreational space use and appropriation, while in Chapter 7 an analysis of observed park use searches with advanced spatial statistical methods for inter- and intra-site displacement.

A promising strategy for recreational facility managers could be a spatial and temporal segregation of the competing and antagonistic uses (Forsyth and Musacchio 2005; Marcouiller, Scott et al. undated). This, on the other hand, would be in opposition to the ideal of urban public space as a place for the “training” of positive values and diversity.

2.3 Summary of Chapter 2

This Chapter has presented relevant concepts from anthropology and environmental psychology about the way human beings perceive and appropriate space. Space is produced by the presence of people and their activities. At the same time, the produced space influences the actions of the same people that create it. This reciprocal relationship can be represented by the attempts of people to achieve a desired level of privacy. The main control mechanism for the regulation of achieved privacy is interpersonal distance. If the achieved privacy is more than the desired privacy, the individual may experience feelings of isolation. If on the other hand the achieved privacy is less than the desired privacy, the individual may experience crowding. The phenomenon of crowding is highly subjective and simple density does not represent it adequately. The crowding may become so intense that occurrences of stimulus overload and social interference manifest: People cannot carry out their desired activities. These situations can lead to conflicts, which in turn lead to processes of exclusion and displacement, thereby reducing social sustainability.

3 Human Spatial Behavior as Spatio-Temporal Process

Human space use and appropriation is a spatio-temporal process, and the observations in three Zurich parks have produced spatio-temporal data. Therefore, the purpose of this Chapter is to situate the thesis into the wider context of the research on spatio-temporal data. After briefly discussing the relevance of time in geographic analysis, I present information on the state of the art of storing, analyzing, and visualizing spatio-temporal data.

3.1 Time in Geographical Information Science

GIScience itself is a new scientific discipline, which roots and defining borders are vague (Pickles 1994). The term itself was introduced by Goodchild (1992). Since then, it has been defined as the basic research field that "seeks to redefine geographic concepts and their use in the context of geographic information systems" (Mark 2003), with research focusing on issues of relational views of geographic phenomena, uncertainty, qualitative reasoning, ontologies and semantics, and cognitive and usability issues (Fisher and Unwin 2005). In addition, Mark (2003) understands time as a crosscutting research theme that is relevant for all research foci.

While time and temporality, motion and change, are essential to many GIS applications, the implementation in common-off-the-shelf GIS products has been weak. These issues will be explored further in the upcoming sections.

3.1.1 *Why Include Time in Geographic Analysis?*

Peuquet (1994; 2001; 2002) argues that whatever spatial process is under scrutiny, inclusion of the temporal element is required. Otherwise, it is impossible to represent change. Parkes and Thrift (1975) also acknowledge that time is a critical factor in explaining cause-and-effect of urban phenomena, so that a temporal paradigm becomes a logical and necessary extension to traditional geographical approaches.

The advent of remotely sensed imagery and the accumulation of other spatio-temporal data, together with increased computing power, have enabled researchers to undertake detailed empirical studies of complex spatio-temporal processes at multiple geographic scales. Unfortunately, the conceptual and practical difficulties in representing and analyzing complex spatial patterns within GIS have caused the temporal dynamics of those spatial patterns to be left largely ignored. Existing spatio-temporal data representations are mainly extensions of traditional, static GIS representations. A great promise of spatio-temporal GIS is the capacity to examine causal relationships and to model and predict their effects. This would allow a shift from “world history models” to true “process models” (Peuquet 1994). The need for a greater and better understanding of geographic processes, through space as well as time, and to effectively access the increasing amounts of available space-time data are main motivations for the ongoing research effort.

3.1.2 *Time Geography and People-based GIScience*

Time-geographic methods share with this research a focus on individual humans and the possibility to visualize co-locations in time and space. For this reason, I present them in more detail. The theoretical branch of time geography is founded in the work of Hägerstrand (Hägerstrand 1970; Lenntorp 1999). He proposed the necessity to analyze processes at the micro-scale with humans as the acting part in our society. In this respect, they are also a response to the criticism on geographic information science and quantitative geography. In a shrinking, shriveling and fragmenting world, people-based time geographic methods are more sensitive to measure accessibility and exclusion (Miller 2005).

Time geography describes the movement of individuals in space-time. Its main analytical tool is the space-time aquarium. In this three-dimensional space, the movements of individuals are mapped as space-time paths, with the z-axis representing the temporal dimension. No movement in space thus corresponds with a vertical line, while the faster the movement, the shallower the slope of the line. The model assumes that a day has 24 hours, nobody can be at more than one place simultaneously, and there is no instant movement from one place to the next. Constraints on the movements are classified into the three types of capability (physical and mental needs), coupling (need of co-location in space and time) and authoritative (administrative and other):

Time geography can be used to identify patterns in the space-time paths of individuals or groups, such as identifying bundles. However, it cannot explain the motives and reasons for these patterns. There is interdependence between the space-time paths of individuals and the constraints imposed upon them: The daily social reproduction of space and time creates and reinforces constraints.

An extension to the original space-time paths is the space-time prism (Miller 1991). It shows the possible locations in space-time that an individual can access. Another addition to time geography is the concept of extensibility, first proposed by Janelle (1973), subsequently refined by Adams (1995) and most recently implemented by Yu and Shaw (2008). Extensibility considers the technical possibilities such as telecommunications to overcome the friction of distance. The digital revolution in telecommunications has reduced or eliminated many coupling constraints.

Two developments have reinvigorated research on time geography: One, the increased computing power available today allows to create and to manipulate space-time aquariums with many space-time paths on desktop computers semi-automatically. Second, travel and activity diaries were once the only means of gathering data. Now, GPS and other location-aware technology are in widespread use. They allow an easy gathering of huge amounts of data. Time geography has recently provided input to research on activity patterns and interactions (Kwan 2004; Yu 2006), analyzing behavior in space and time (Kritzler, Raubal et al. 2007; Laube, Dennis et al. 2007; Shoval and Isaacson 2007), measuring accessibility and exclusion (Wu and Miller 2001; Miller 2005), and fighting crime (Kapler and Wright 2004).

3.2 Representing Spatio-Temporal Phenomena

After some general remarks on the spatial and temporal dimensions of data, the aspects of storing, analyzing, and visualizing spatio-temporal data are briefly covered.

3.2.1 *Representing Time and Space*

There are several analogies between the representation of time and space.

At the conceptual level, there is a distinction between states or processes and events. An event is a single, undividable unit, with a definite beginning and end. If they are the same, the event is instantaneous. Events can be counted, and in this respect are analogous to geographic objects. In contrast, a state or process is something ongoing. States and events provide us with two different ways of conceptualizing what goes on in time. Either the history of the world can be presented as a sequence of sets of state values, or it can be presented as a collection of event occurrences, each assigned to a particular time. There is a strong analogy here with the field-based and object-based approaches of the spatial domain, and by implication with the absolute (states) and relational (events) distinctions. Peuquet (1994) argues that they are complementary and not contradictory.

Another similarity is that space and time are continuous, but for objective measurement are broken down into discrete units. Although most natural phenomena are changing continuously, from the viewpoint of practice, the discrete model is preferred over the continuous model because measures are taken at specific points in time and the representation at the machine level has to be discrete (Cheng 2005).

Scale is also important: The temporal resolution or granularity of discrete models of temporal data is sometimes called a Chronon. Very often, a data set has several granularities. The choice of temporal scale has similar implications as the spatial scale. A distinct spatio-temporal pattern at one scale may disappear into chaos at another scale (Parkes and Thrift 1975; Peuquet 1994), while a coarse granularity can extend the modifiable areal unit problem of spatial data into the temporal domain (Peuquet 2001). When using the lowest common granularity, a lot of information is lost. Therefore, spatio-temporal databases should allow for multiple granularities (Hornsby and Egenhofer 2002).

The main difference between time and space is that movement in time is unidirectional. However, Ott and Swiaczny (2001) and Cheng (2005) propose a fundamental distinction between linear and cyclic time, them being the two major metaphors deeply embedded in human thought.

The integration of time and space into a single conceptual framework has been the subject of extensive research (Langran 1992; Galton 2001; Peuquet 2002), resulting in many different concepts. An attempt to unify the multitude of different concepts and move towards a general theory of representing spatio-temporal phenomena has recently been undertaken by Goodchild, Yuan et al. (2007).

3.2.2 *Storing Spatio-Temporal Data*

The concepts for modeling spatio-temporal phenomena encounter many problems in practical applications, which is why many have not moved beyond the prototype or proof of concept stage. Work on space-time database design has progressed separately in the DBMS and GIS communities. Several reviews try to summarize the different approaches (Clifford and Tuzhilin 1995; Abraham and Roddick 1999; Koubarakis and Sellis 2003).

The two most common implementations are the versioning/time stamping model and the snapshot/time slice model. Main reason for their prevalence is the relative simplicity with which these models can be implemented by using existing software.

In the versioning/time-stamping model, time is an attribute of objects. Each creation or end of objects and change of attributes adds an entry in the database that has a time stamp. This model only supports valid time but allows working with multiple granularities. The different versions of an object are dispersed over the table in several unconnected tuples. This makes it difficult to follow the history of an object.

In the snapshot/time slices model, time is an attribute of space. Each layer of data is the complete collection of temporally homogenous entities of a theme. Changes are only inferable by direct visual comparison of the layers. The main drawbacks are the need for storing highly redundant data, and the lack of information about steps between snapshots, and triggers for events. Any events that took place between snapshots or time slices are not recorded. Identity change of objects is also difficult to pinpoint. Thus, the capacity for complex queries is limited.

Other approaches add a temporal extension to entity-relationship or object-oriented models (Tryfona, Price et al. 2003; Parent, Spaccapietra et al. 2006). The spatio-temporal entity relationship model (STER) builds on the entity relationship model, adding a temporal extension. It is possible to handle complex spatial entities and bidirectional changes of spatial and temporal semantics. Spatio-temporal object-oriented models are an extension of object-oriented models, where the object classes have spatial temporal characteristics. A single object can represent the whole history of an entity, facilitating queries and enabling efficient processing of temporal data. The event-oriented model focuses on the temporal aspect and has the capacity for spatial-temporal queries. It represents temporal changes on a time line. Each event has a time stamp connected with a list of components showing the changes (Claramunt and Thériault 1995; Peuquet and Duan 1995)

An important general distinction is that between the time belonging to an entity of the real world (valid time) and the time something is recorded in the database (transaction time). If both are recorded, database design is bi-temporal.

Looking at common-off-the-shelf software packages, it is striking how few of these concepts have been implemented. There are two main reasons why functional space-time systems not gone beyond the prototype stage. For one, GIScience had remained for a long time in a traditional, static cartographic paradigm. Second, emphasis has been placed on short-term and implementation-oriented solutions to specific problems. “Jumping-in” and using a familiar paradigm can be considered a rational approach (Peuquet 2001).

3.2.3 *Analyzing Spatio-Temporal Data*

A key concept in the analysis of spatio-temporal processes is the representation of change. In early research (Berry 1964; Langran 1992), the central unit of analysis was the spatial theme or layer, and change was inferred by comparing spatial snapshots.

Influenced by object-oriented views, this concept has shifted towards the association of change with individual features (Beard 2007). Termed the object change view by Worboys (2005), this approach is closely associated with versioning or time-stamping data models: While a feature (object) has one unique, persistent identifier, any changes to its spatial or non-spatial attributes are recorded. In contrast, a truly event-based model records affected features as attributes of events (Claramunt and Thériault 1995; Peuquet and Duan 1995; Worboys 2005).

A multitude of classifications for changes exists (Moreira, Ribeiro et al. 1999; Yattaw 1999; Hornsby and Egenhofer 2000; Andrienko, Andrienko et al. 2003; Cheng 2005). In many cases, the analyst needs to consider several types simultaneously, which include changes of geometry, topology, attributes, and combinations of these. Changes in identity are also possible, e.g. splitting of objects (Hornsby and Egenhofer 2000). Cheng (2005) identifies three types of spatio-temporal behaviors of data: Continuous change (objects are always in a changing state), discrete change (objects are always in static states but change instantaneously with events) and stepwise change (objects are sometimes static and sometimes change).

Because most of the advanced querying and analysis methods have not been implemented in standard GIS packages, I do not go into more detail after this brief introduction, instead referring to Chapters 5 and 7 for the actual analysis of the observation data.

3.3 Visualizing Dynamic Geographic Phenomena

3.3.1 *From Cartography to Geovisualization*

Cartographers primarily regarded maps as a medium of communication to the public (MacEachren 1995). However, in the past two decades, researchers began to think of maps as tools that support visual thinking, knowledge construction, and decision-making. Geovisualization (short for geographic visualization) has partly replaced the terms “cartography” and “map” in the recent scientific discourse. As a cross-cutting research theme (Mark 2003), it has been the focus of much research activity (MacEachren 1994; MacEachren and Kraak 1997; Fairbairn, Andrienko et al. 2001; MacEachren and Kraak 2001; Andrienko, Andrienko et al. 2003), and many results have found their way into the geographic curriculum (Hearnshaw and Unwin 1994; MacEachren and Taylor 1994; Slocum 2005). Nevertheless, the research agenda is still large (Gahegan 1999; Slocum, Blok et al. 2001; Dykes, MacEachren et al. 2005; Slocum 2005; Andrienko, Andrienko et al. 2006; Andrienko, Andrienko et al. 2007).

Aside from full-scale books on the topic of geovisualization (Dykes, MacEachren et al. 2005; Andrienko and Andrienko 2006), recent state of the arts focused either on visualization technique (e.g. Andrienko, Andrienko et al.(2003) on exploratory visualization; Harrower (2004) on animated maps; Roberts (2007) on coordinated and multiple views) or visualization content (e.g. AvRuskin, Jacquez et al. (2004), on epidemiologic data; Brunsdon, Corcoran et al. (2007), on crime data; Kwan (2004), on time-geographic research; MacEachren, Robinson et al. (2005), on uncertainty). Many advanced techniques have yet to find their way into commercially available, off-the-shelf software products (Parkes and Thrift 1975; Langran 1992; Peuquet 1994; Ott and Swiaczny 2001; Peuquet 2001). Nevertheless, a systematic evaluation of the advanced techniques is lagging behind even more, so that "there is the very real risk that mapping technology is outpacing cartographic theory" (Harrower and Fabrikant 2007).

3.3.2 *Visualizing Spatio-Temporal Data*

For visualizing multi-variate spatio-temporal data, computer cartographers and analysts have employed several strategies. An early classification has been proposed by Monmonier (1990), while Vasiliev (1997) focused on traditional static maps. I adopt a classification by Peuquet (1994), identifying three basic strategies that may be combined:

Symbology as sign-vehicle: Examples include spring graphs, isochrones and geometrically distorted cartograms (Vasiliev 1997). Any graphical representation is a scene, which is composed of graphical primitives that visually encode the data. The major decisions when constructing a scene are mainly which layers or channels of data to include, and which visual variables to assign to which feature attributes (Gahegan 2000). There are several configurable visual variables, such as position, dimensions, size, shape, orientation, color (either RGB or hue, saturation, intensity), transparency and material properties (MacEachren 1995; Bertin 1999). Experiments have shown that shape, color and size are separable, pre-attentive and processed parallel, hence they are suitable for simultaneously encode multivariate datasets visually. Employing the third dimension is also an intriguing option to display temporal data (Wood, Kirschenbauer et al. 2005). Space-time cubes can be used either to display the temporal attributes of phenomena that have a fixed location, such as traveling times or opening hours of service locations; or those that change location, such as individual moving point data (Wu and Miller 2001; Kwan and Lee 2003; Kapler and Wright 2004; Kraak and Koussoulakou 2005; Yu 2006). Forer (1998) has extended the discrete representation of the space-time cube to a full continuous 3D-raster conceptualization with taxels as main symbolization element. Brooks and Whalley (2007) demonstrate a multilayer hybrid 2D/3D display technique to overcome some of the 3D related problems, including self-occlusion of the data. Brunsdon, Corcoran et al.(2007) extend kernel estimations into the third dimension.

Time as sign-vehicle: Dynamic visualizations offer an additional representational dimension and thereby more visual variables that can be used to display information: These include duration, rate of change, order, display date, frequency, and synchronization (DiBiase, MacEachren et al. 1992; MacEachren 1995; Blok 2005). Dynamic visualizations seem like a "natural" or "intuitive" (Acevedo and Masuoka 1997) choice for visualizing time and change. Animations are defined as sequences of static graphic depictions (Buziek, Dransch et al. 2000). Lobben (2003) developed a categorization scheme based on the display characteristics of time, variables and space. Harrower and Fabrikant (2007) add the characteristics of temporal scale (ratio between real world and animation time), temporal resolution or granularity and pace (amount of change per time unit). Although first animations date back as far as 1970 (Tobler 1970), and much pioneering research has been conducted 15 years ago (DiBiase, MacEachren et al. 1992; Dorling and Openshaw 1992), photo-realistic scenes and animations have become feasible only recently. Although animation techniques provide a powerful and visually effective means for discovering causes and effects, there are difficulties involved. Bertin (1999) criticized that motion distracts from the interpretation of the data. Tversky, Morrison et al. (2002) failed to find benefits of animation for conveying complex processes. The key to successful animations is to account for human perceptual and cognitive capabilities (Rensink, O'Regan et al. 1997; Bunch and Lloyd 2006). Information overload is a common problem with animations (Harrower and Fabrikant 2007). Tversky, Morrison et al. (2002) formulate two principles that successful animations should adhere to: Congruence (natural correspondence between change over time, animation core and essential conceptual information conveyed) and Apprehension (slow and clear enough for the observer to perceive and understand changes in relations between elements and sequence of events). Andrienko, Andrienko et al. (2005) argue that a main problem with animations is the missing opportunity for an analyst to compare directly states at different moments in time. Other techniques and tools must support comparison and trend detection. Rana and Dykes (2003) have proposed improvements for dynamic raster surfaces that rely on spatial and attribute smoothing, temporal interpolation, derived morphometric surface features, graphic lag or fading and conditional interactivity.

Multiple views: Coordinated multiple views display the same data in different ways (Roberts 2007) and are used mainly for exploratory analysis. Small multiples use the same type of display (e.g. map section) for visualizing distinct attribute sets of multi-dimensional datasets (Tufte 1991). In this context, Egbert and Slocum (1992) devised an exploration system for choropleth maps. Building on this work, Brunsdon (2001) and Carr, White et al. (2005) created tools that allow the display of small multiple conditioned (choropleth) maps for hypothesis generation. Griffin, MacEachren et al. (2006) have evaluated the use of small-multiples and animations for visually identifying space-time clusters. They conclude that animated representations enabled users more often to identify correctly clusters and patterns. Slocum, Sluter et al. (2004) agree that animations were best suited for identifying general trends, while static small-multiples were suited best for comparing specific time points. Blok, Köbben et al. (1999) examine the combination of multiple views and animations by juxtaposition. It still has to be examined whether multiple animations do not lead to a perceptual and cognitive overload of the viewer.

3.3.3 *Problems of Technology-Driven Development*

During the last decade, encouraged by cheaper and more readily available hardware, researchers have begun to develop a large number of advanced visualization tools. These tools available today are largely hosted in closed systems that cannot easily be modified or integrated within each other. Moreover, rarely has enough effort gone into positioning and integrating these tools into the wider scientific process, so that a researcher can seamlessly move from one tool to another, back and forth, as activities dictate and as it is common in scientific research. There are mainly two reasons for this situation: Academics typically build tools to test and present ideas, not to become operational within the scientific community. The most effective way to build such tools is to close as many aspects of the systems as possible, so development is less time-consuming. From a commercial perspective, open systems present the risk of potential market share loss. Another problem is that most tools focus on the data at hand, and not on conceptual studies, thus being less useful for synthesis activities (Gahegan 2005). As a result, many tools and developments do not build on existing knowledge and software but instead reinvent the wheel repeatedly. Generally, the tools can be grouped into two categories: Those originating from geosciences, and those originating from information visualization. The former usually focus on analytical functions, with visualizations added as an afterthought that is difficult to automate. The latter are specialized on exploring multi-variate data, usually without an explicit spatial component. The technical and computational demands for dynamic 3D-visualizations are still high, mainly because the available software is either geared towards animations (not supporting spatio-temporal data and analysis) or data exploration and analysis (not supporting interactive, on-the-fly dynamic 3D-visualizations).

3.4 Uncertainty in Spatio-Temporal Data

The terms “inaccuracy”, “inexactness”, “fuzziness”, “incompleteness”, “vagueness”, “imprecision”, “ambiguity” and “error” all have been used to describe various aspects of uncertainty (Peuquet 2001; Duckham and Sharp 2005; Longley, Goodchild et al. 2005; MacEachren, Robinson et al. 2005; Thomson, Hetzler et al. 2006).

There is inherent inexactness in all spatial, temporal, and spatio-temporal data. One reason for this is the artificial discretization required by of the computing environment. Another is the necessary classification of data and definition of objects (Peuquet 2001). Nevertheless, uncertainty is often excluded from data representations and analysis. One reason is that current mathematical representational tools do not lend themselves to dealing with incompleteness. Another reason is that science has traditionally viewed uncertainty as something to be overcome rather than openly acknowledged (Peuquet 1994). Inconsistency and uncertainty are usually resolved or eradicated at the earliest opportunity, and the underlying observations discarded. This information transformation is usually unidirectional (Duckham and Sharp 2005).

There are several formal models for handling uncertainty. Stochastic models are by far the most commonly used model in geographic information. They assume that imperfection is a result of random variation of essentially crisp and knowable phenomena, whose variables are statistically independent. Both assumptions are not true in many cases, because spatial data rarely has random variation and spatial autocorrelation violates statistical independence. Another approach is fuzzy set theory. In a fuzzy set, each element is identified with a real number from the interval [0, 1] that describes the degree of membership of that element to a set X. One of the remaining difficulties is the assignment of fuzzy membership values, which is always to some extent subjective (Fisher 2000). In addition, fuzzy sets have been criticized as being actually Boolean in nature, with the fuzzy membership function being no more than the additive sequence of multiple Boolean sets. In contrast, three-valued logic classifies elements either as in, out or indeterminate member of a set X. One of the most common three-valued logic systems is rough set theory. Rough sets can assume a variety of interpretations, including inaccuracy, imprecision and vagueness. It has the advantage of simplicity, but may not be sophisticated enough to provide an adequate model of imperfection in many cases (Duckham and Sharp 2005).

While there have been numerous attempts at categorizing uncertainty (see previous Chapter), most approaches to uncertainty visualization have treated uncertainty as a single attribute of data. This creates a mismatch between efforts to conceptualize it and those to represent it visually (MacEachren, Robinson et al. 2005).

A common distinction is between intrinsic and extrinsic methods for visualizing uncertainty. Intrinsic techniques change the appearance of an object based on the level of uncertainty, while extrinsic techniques use additional symbols for the representation of uncertainty. The most basic approach to visualize uncertainty intrinsically is to apply directly some of the standard visual variables. MacEachren, Robinson et al. (2005) argued for an extended set of variables for visualizing uncertainty: Color saturation, crispness (contour crispness and fill clarity), transparency (also termed fog) and the resolution of raster images and vector lines. Concerning the effectiveness of the different visualization methods, studies have shown that color value (or darkness) is more consistently associated with uncertainty than color saturation (or grayness). Results were best with a lighter value representing more certain information and darker values representing less certain information. If color value cannot be used, finer texture followed by higher saturation should be used. There have also been attempts at using animation techniques for visualizing uncertainty, for example by changing the duration of a representation. Finally, another approach is to generate multiple realizations based on different processing and/or interpretations of the data, and then use a comparison of these different representations to convey the inherent uncertainty (MacEachren, Robinson et al. 2005).

Usability studies showed that experts preferred extrinsic methods, while decision makes preferred intrinsic methods (MacEachren, Robinson et al. 2005). Expert users also tend to respond by incorporating probabilities to represent uncertainty mathematically, while naïve users prefer an intuitive, heuristic approach by relying on experiences and stereotypes. All users should be in control of the uncertainty depictions, e.g. through setting a threshold value beyond which data is not displayed at all. Another study (Hope and Hunter 2007) showed the impact of introducing thematic uncertainty to be severe on the outcomes of decision making processes: The test subjects showed a strong bias against information labeled as uncertain, even if this uncertainty implied the chance for a “better” decision. Other experiments suggest that the decision task influences the subject’s response to uncertain information more than the way it is visualized (Deitrick 2007). Still, neither the impact on the analysis and decision-making processes nor the best ways to visualize uncertainty at all are yet fully understood.

3.5 Summary of Chapter 3

In this Chapter, I have presented relevant concepts from several fields of geographic information science, database design, and scientific visualization. The inclusion of time into an analysis is in most cases necessary to represent the phenomena under scrutiny in an adequate manner. The amount of data with both a spatial and temporal component is increasing rapidly. Several new approaches in database technology and design, quantitative analysis methods and scientific visualization have been proposed to deal with the large amounts of new high-dimensional data. In the field of visualization, the last decades have brought a multitude of new techniques that have become feasible. However, most advanced techniques for the handling of spatio-temporal data have in common that they have been rarely implemented in available products yet. Still, snapshot or timestamp models, coupled with simple, low interactive animations are the standard, while advanced object-oriented spatio-temporal data models with three-dimensional, highly interactive visualization techniques remain confined to closed systems, which were developed and used within specific research contexts. Moreover, the effectiveness of different visualization techniques for specific tasks has not yet been evaluated systematically. The suitability of specific uncertainty representations and their visualization presents additional unknowns.

PART III: MODELING & METHODOLOGY

4 Modeling Human Space Appropriation

Several implications for this thesis arise from the literature review in the preceding sections. The difficulties described in measuring and dealing with crowding and conflict in recreational settings suggest the need for new approaches. To the knowledge of the author, no other research has yet attempted to tackle the phenomenon of crowding and conflict with explicitly spatial analysis methods at the micro-scale of individuals.

This chapter deals with the first research question from Chapter 1: What model could be used for the analysis of spatio-temporal pattern of space appropriation and the identification of potential crowding?

This rather broad question can be broken down into two questions that are more specific and guide the remainder of this chapter:

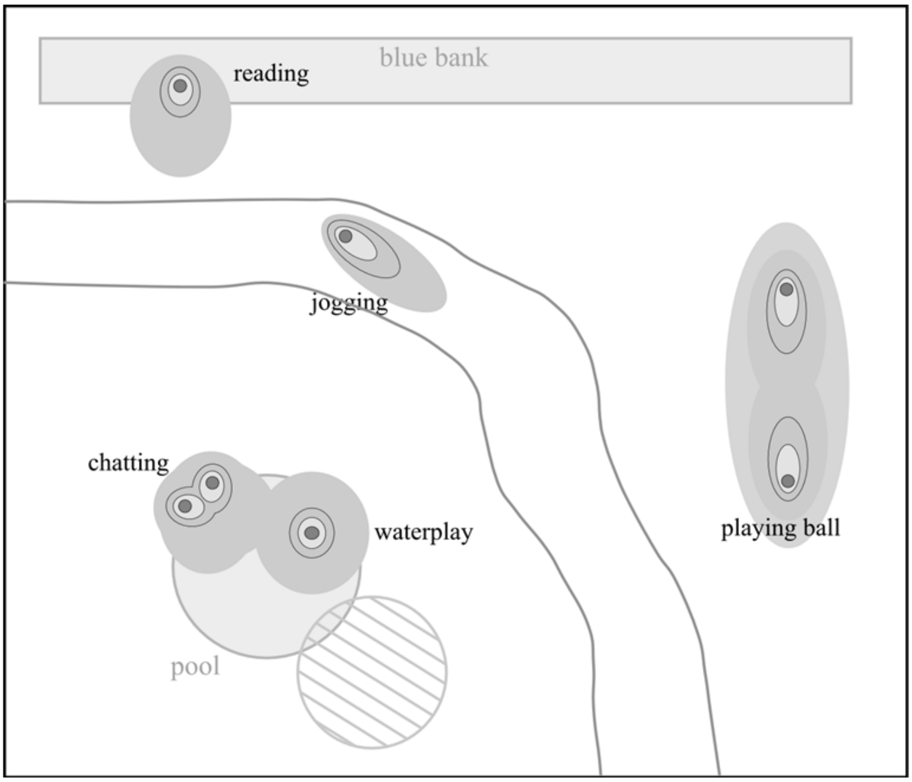
- How can we conceptualize individual human appropriation and usage of space, and derive a model of it?
- How can we capture and measure potential crowding, competition for space, and resulting conflicts?

Accordingly, I synthesize concepts and theories described in Chapter 2, and introduce a new concept for the representation of recreational activities. It allows the modeling and quantitative analysis of human space use and appropriation, and subsequently the representation of potentially crowding situations.

4.1 Conceptualizing Active and Passive Components

The model of human space appropriation that I will outline in this section builds on the work of Altman (1975) and Hall (1966). The personal distance zones introduced in Chapter 2 form the passive personal spaces that park visitors would prefer to have to themselves for achieving the desired level of privacy. As already stated, they are the most important interpersonal control mechanism. However, they represent only one aspect of human space appropriation. It is also necessary to introduce an active component: The spaces actually occupied by the activities of the park visitors. Clearly, the type of activity primarily defines these active spaces. Each type of activity requires a specific active space that I call the activity's *footprint*. Some examples are given in the following figure:

Figure 4-1: Examples for Activity Footprints



Source: Timpf, Ostermann et al. (2006)

Several parameters define the activity footprint: Intensity, size, shape and direction. While direction is inferable from the facing of an individual and influences shape, the remaining parameters are yet unknown and will have to be estimated from the analysis of the observation data.

However, in order to be able to observe activities systematically, an a-priori categorization is necessary. Arguing from preliminary observations and the communication cues described in Chapter 2, I propose the following types of activities in order to determine distinctive activity footprints:

- Static Solitary: Non-interactive activities that involve almost no movement, such as sleeping, reading, or working. Sensory output is restricted to visual codes.
- Static Interactive: These activities involve communication and thereby have a greater effect on the surrounding space. Examples include chatting, observing of

other park visitors, musical performances, attending children, or playing board or card games. Sensory output is audio-visual.

- BBQ and picnicking: This is a separate category from the static interactive type, because the sensory output is not only audio-visual but also olfactory. This may, depending on the amount of smoke generated and the prevailing wind direction, cause a very large and irregular activity footprint.
- Dynamic Regular: All activities that involve a lot of movement on the part of the participants, but have more or less regularly define boundaries. Still, the activity footprint is larger than those boundaries, because some action will take place outside of them. Examples include mainly ball games such as football, but also badminton or similar games. The sensory output is mainly audio-visual, but it might also include touch.
- Dynamic Irregular: These activities involve lots of movement, but have no defined borders. Examples include chasing around, or games where the direction is unpredictable such as Frisbee. Sensory output is again audio-visual with potentially touch.
- Infrastructure: Activities using the park's equipment such as playgrounds, water pools, etc. They are bound to certain places because of the non-movable infrastructure. In the terms of proxemics, they create fixed-feature spaces. Output is again audio-visual, with only a low probability of touch.

In many cases, the actual activity of a park visitor might combine several categories, such as BBQ using infrastructure provided by the park, or the combination of activities such as attending children while playing a game. How such cases are handled will have to be determined during the empirical phase.

4.2 Determining Crowding and Conflict

The model assumes that a potential for crowding exists when personal spaces and incompatible activity footprints of other park visitors overlap, thus creating a situation of stimulus overload for at least one of the involved parties. This stimulus overload can result in several coping mechanisms describe in Chapter 2. Such conflicts between the involved parties do not have to be openly visible.

For the compatibility of activity types, the ordinal scale from Manning and Valliere (2001) and Scott et. al. (unknown) is adopted in Table 4-1. Because activities that rely on water or the park infrastructure such as playgrounds are confined to certain areas and are less likely to interact with the other types of activities, they were omitted from the table.

Table 4-1: Level of Compatibility between Activity Types

[Row] is to [Column]	Static Solitary	Static Interactive	Eating	Dynamic Irregular	Dynamic Regular
Static Solitary	Complemen-tary	Complemen-tary	Complemen-tary	Competitive	Antagonistic
Static Interactive	Complemen-tary	Complemen-tary	Complemen-tary	Competitive	Antagonistic
Eating	Complemen-tary	Complemen-tary	Complemen-tary	Competitive	Antagonistic
Dynamic Irregular	Antagonistic	Antagonistic	Antagonistic	Competitive	Antagonistic
Dynamic Regular	Antagonistic	Antagonistic	Antagonistic	Antagonistic	Antagonistic

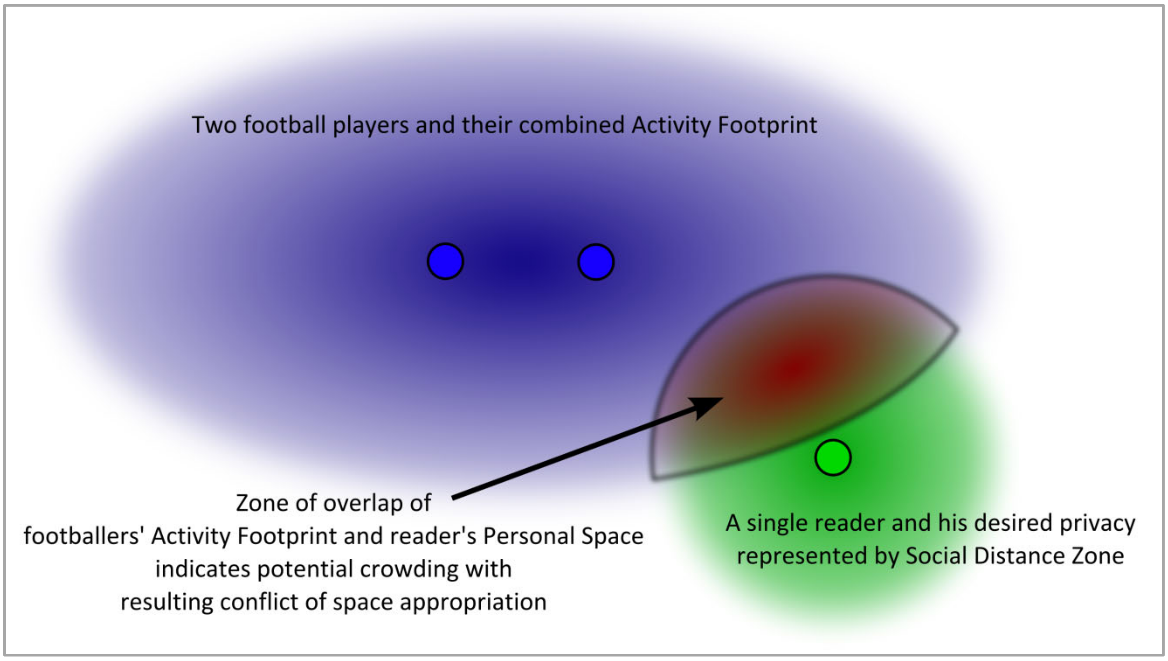
Source: adopted from Manning and Valliere (2001)

It is obvious that the non-dynamic activities are mostly complementary, i.e. they do not exhibit a negative influence on each other, unless the general level of activity does not exceed a certain threshold. The irregular dynamic activities are antagonistic to most other activities, but react more flexible towards all other activities, because the location can usually be changed with ease. Regular dynamic activities are the most incompatible to all types, because they prohibit other activities from using the appropriated space while at the same time they are inflexible to change location. The speed with which an activity is carried out influences its acceptance from park visitors pursuing other activities, e.g. cycling is more prone to incite conflict than jogging (Arnberger 2005)**.**

I assume that there are no conflicts of space appropriation within one group of visitors. Members of a visitor group obviously know each other and participate together in various activities. Accordingly, the first step is to group the individuals according to group membership as recorded during the observations. If individual group members carried out several activities, the prevalent one is chosen as group activity via a simple count of each activity type occurrence. In case of a draw, the more space-consuming activity is chosen.

Consider the example in Figure 4-2 of two football players (blue) and a reader (green) and their respective activity footprints and personal spaces where intrusion is experienced as a disturbance. The football players' activity footprint is large and disturbs the reader already at her social distance zone, provoking a stimulus overload and resulting feeling of crowding from the reader's perspective. Reversing this example (not shown), the small activity footprint of the reader will rarely overlap the very small personal spaces in which the football players feel disturbed. This is due to their physical activity, so that only intrusions within the personal distance zone disturb them (and probably only if that intrusion constitutes a foul by a fellow player).

Figure 4-2: Potential Crowding and Conflicts in Space Appropriation



Source: own design

Note that for simplicity's sake the individual personal spaces and activity footprints are circular, although as mentioned above, a goal is to adjust the shape and direction according to the type of activity.

There are three aspects not yet included in this model. First, as Freedman (1975) states, crowding is not per se a negative situation, it rather amplifies already eminent positive or negative emotions. Considering the fact that many people enter a park in rather relaxed and open-minded mental state, high density can also lead to positive interaction. This is mostly observable between smaller children who tend to play together (conflicts arise rather from sharing equipment). It is difficult to represent this in a model, because of the unknown state of mind of the individual park users. The matrix of activity types could show where to expect conflict and where positive interaction might result (see Table 4-1). In an improved model, the motivations could be included by inferring from the results of in-depth interviews conducted in parallel to the observations. Second, I conceptualize crowding in the sense of Altman (1975), i.e. the level of achieved privacy is less than the level of desired privacy, resulting in stimulus overload. The aspect of social interference has not been included yet. The reason is that social interference would be the result of overlaps between activity footprints. However, their parameters cannot be defined adequately yet. Third, ethnicity is not part of the model. This is because in the case study, it is not possible to determine ethnicity something easily observable like skin color. It can be implemented in an improved model without difficulty.

4.3 Quantification of the Parameters

A quantitative representation of human space use and appropriation should adequately represent the irregularity of human space appropriation, namely vague irregular boundaries and non-linear distance decay of intensity. Such a representation should also be flexible enough to be adjustable to different environments.

The two main components (personal spaces and activity footprints) are influenced by several variables, including activity type, age, gender, and ethnicity. However, the model focuses exclusively on activity type for the time being. As argued in the preceding section, ethnicity is difficult to operationalize as independent variable. Age has not been identified in the literature as an influence on perceived crowding and conflict, and probably is highly correlated with activity type (see section 7.1.1 for result confirming this assumption). An influence of gender is subject to debate. I also presume that activity type largely depends on the other variables, which has been suggested in the literature (see Chapter 2) and indeed been verified by the analysis of the observational data (see Chapter 7). Therefore, a focus on activity type is sufficient for the start.

The type of activity determines the radius of the personal space, i.e. the personal distance zone that a park visitor claims for him- or herself. The following Table 4-2lists the activity type and their corresponding personal distance zone:

Table 4-2: Activity Type and Personal Distance Zone

Activity Type	Personal Distance Zone
Static Solitary	Far Phase Social Distance (3 m)
Static Interactive	Close Phase Social Distance (2 m)
BBQ and Eating	Far Phase Social Distance (3 m)
Dynamic Irregular	Far Phase Personal Distance (1 m)
Dynamic Regular	Far Phase Personal Distance (1 m)
Infrastructure	Far Phase Personal Distance (1 m)

Source: own design

The size and shape of activity footprints is more difficult to determine. If the facing of a park visitor is known, the most common shape of activity footprint for more static activities would be an ellipse, with the park visitor being one of the two foci. Otherwise, a shape other than a circle is not feasible to use.

Additionally, a weight for the type of conflict can be set, e.g. the intrusion of a footballer's activity footprint into a reader's personal space can be set to be more conflict-inducing than vice versa (compare Table 4-1).

4.4 Capturing Processes of Displacement and Exclusion

As I have argued, socially sustainable space appropriation is not possible to achieve with processes of exclusion and domination. In order to detect them, it is necessary to reveal potential crowding and conflicts in space at the micro-scale of individual park visitors. While the proposed model is intended to provide information about on-going crowding situations, it cannot detect processes of exclusion or displacement that have already resulted from persistent conflicts of space appropriation. A complementary approach therefore is to analyze the space appropriation on the level of observed parks as a whole. This approach might hint at processes of displacement and exclusion that remain undetected otherwise. There are two indicators for displacement and exclusion:

- At the micro-scale of single parks, the clustering of spatio-temporal distribution of activities allows an estimation of the displacement processes taking place. While it is not possible to deduce inter-site displacement, intra-site and temporal displacement could be the result for a significant spatio-temporal clustering.
- At the meso-scale city of neighborhoods, a general indicator for a sustainable appropriation of public space is the observed composition (age, gender) of park visitors. If it differs largely from the composition of the neighborhood population and

there are no other public open spaces to compensate, it is a strong hint for the exclusion of a specific socio-economic group.

Additionally, directly observed conflicts and their results should be recorded and used as a basis for refining the model.

The suitable spatial and statistical analysis methods will be presented in the next Chapter.

4.5 Summary of Chapter 4

This Chapter introduces a new concept for the modeling of human space appropriation. I argue from the research presented in Chapter 2, that it is possible to represent space appropriation using a model, which has two main components. These two components represent the space actively used, and the space claimed by everyone as personal. They are called activity footprints and personal spaces, respectively. Together, they enable a representation of the interaction between individuals in their attempts to achieve a desired level of privacy. An overlap of one individual's activity footprint with another individual's personal space could represent a potential for stimulus overload, perceived crowding, and finally for conflict. The size, shape, and direction of the activity footprints and personal spaces depend on the variables of activity, gender, age and ethnicity. To begin with, the model focuses on the most important variable, which is type of activity.

5 Research Methodology

In this Chapter, I describe the methods that were employed during all stages of the research. Its main purpose is to address the second research question (see Chapter 1):

- Which methods are suitable for computing space appropriation, analyzing the observation data, and visualizing the results?

The Chapter starts with an outline of the conceptual stages of the observations. This is necessary, because the expected type of data determines the selection of suitable analysis and visualization methods. The rest of the Chapter roughly follows the structure of the preceding Chapter: First, suitable methods for the representation and spatial analysis of the active and passive components of the model are presented, including the computation of potential crowding. The inclusion of the temporal dimension is a prerequisite for analyzing space use and appropriation and introduced next. Then, I describe global analysis methods for the detection of displacement and exclusion. Finally, the visualization methods are briefly presented, including a simple evaluation framework.

5.1 Conceptualizing the Observations

In order to ground the model of space appropriation in reality and provide some guidelines on park design and management, data on the actual usage of public parks is needed. Although the facility management of Zurich's public parks (GrünStadtZürich) has conducted frequent surveys of the parks' acceptance, the results give no information about actual usage patterns in specific parks.

Other studies have mapped park usage to a certain extent (Paravicini 2002; Low, Taplin et al. 2005), but none have data with individual visitors' spatio-temporal location and attributes. A new toolkit and method had to be developed to capture and display the indispensable data.

5.1.1 *Systematic Observations*

One way to capture the required data is by systematic observation of activities in public parks. Systematic observation is especially suited to gain data about everyday activities of people (Meier-Kruker and Rauh 2005; Reuber and Pfaffenbach 2005). In order to be systematic, it has to fulfill four requirements:

1. A clearly defined specific research purpose: This has been addressed in Chapters 1 and 4.
2. Systematic planning: The timing of the observations is a crucial prerequisite to acquire representative results (more on this in section 6.4).
3. Systematic recording: Clearly defined categories are necessary (see below).
4. Repeated evaluation: Controlling the validity, reliability, and precision is likewise indispensable (more on this in section 6.4).

A great advantage of observations is that the situation is less artificial than during an interview. A potentially direct influence of the researcher on the subject of investigation is minimized, so one can capture what people actually do, and not what they say they will or would do. Quantitative observations favor non-participating, and structured observations. What this means in detail will be discussed now.

There are three principal criteria that allow distinguishing between different forms of observations (Meier-Kruker and Rauh 2005; Reuber and Pfaffenbach 2005):

- Participating or non-participating
- Open or undercover
- Partly or fully structured

The distinction between participating and non-participating observations is not to be understood as a clear-cut separation of categories. Instead, the two form the opposite poles of a continuum. Sometimes, interaction is inevitable. In this particular case, the observers occupy and appropriate space for themselves and thereby influence the use and appropriation of space by other park visitors. Based on the pilot studies, I argue that the influence of two to three observers on the usage of a park with more than one hectare of land area and several dozen simultaneous visitors is negligible.

An observation can be revealed to the observed individuals or remain undercover. Which form of observation is chosen depends on the research interest and the setting. In this specific case, it is neither possible nor advantageous to inform everybody of the observation. Since the setting is a public space, and the data is anonymized (no videotaping), the issue of privacy and control of personal information is noncritical.

In order to be usable for computer-aided spatio-temporal analysis, the data has to be captured in the most structured way possible to avoid additional uncertainties associated with a later recoding. Therefore, an emphasis was placed on a careful selection of categories. The variable categories have to fulfill these requirements:

- One-dimensionality of measurement
- Exclusivity of the categories, meaning that each event can be attributed to only one category
- Completeness of categories , i.e. all observations must fit into one category
- Real-world equivalency of categories
- Reduction to the lowest possible number of categories for practical reasons

Variables of interest are gender, age, activity type, group affinity, space, and time. The following tables show the categories for age (Table 5-1), gender (Table 5-2), and activity type (Table 5-3):

Table 5-1: Age Categories

Age Category	Description
Infants	not capable of active use of park space (i.e. not able to walk yet)
Children	up to the age of about 12
Teenager	between 13 and 20; signs for adolescence include style of clothing, no „children's games", couples, consumption of alcohol and cigarettes
Young adults	between 21 and 30; mostly without children
Senior adults:	about 31 to 65 years of age, many in family groups
Seniors:	park visitors most likely to be old enough for retirement

Source: the author

Table 5-2: Gender Categories

Gender	Description
Male	Male visitors
Female	Female visitors
Unknown	Indeterminable gender, mostly expected for the age category "infants".

Source: the author

Table 5-3: Activity Types

Activity Type	Description
Static Solitary	Solitary activities on the spot, e.g. sun-bathing, sleeping, reading, working
Static Interactive	Interactive activities on the spot, e.g. observing, talking, watching over child-ren; board or card games
Eating	Preparation and/or consumption of food and beverages, e.g. picnicking, eating, drinking, BBQ
Dynamic Irregular	Games that involve lots of movement on an irregular area, e.g. chasing, romping or frolicking around
Dynamic Regular	Games that involve lots of movement on a more clearly defined area, e.g. football, badminton, martial arts
Playgrounds	Activities that use the park infrastruc-ture, e.g. playgrounds
Water	All activities that involve water

Source: the author

The variables space and time will be recorded by digitizing points in a geographically referenced space and noting the time stamp. Group affinity will be an unique identifier, or Group ID, which is assigned to the individuals that are part of the group.

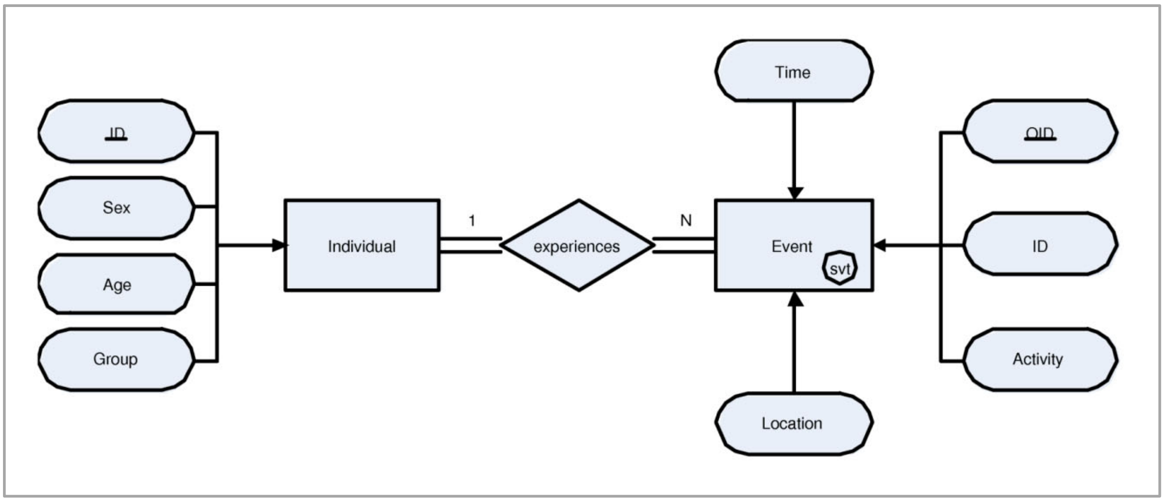
Still, the author is aware of several problems that cannot be eliminated. Standardized, structured observations move the subjective element of the empirical work to the beginning of the design and implementation process (“you can only observe what you already know”). In addition, the construction of categories results from underlying hypothesis, thus it reproduces the ideas of the researcher. Further, any observer and situation dependent interferences and interactions are neither unavoidable, nor controllable or exactly documentable.

However, the author remains convinced that these caveats, once acknowledged and taken into account, do not render the research approach less useful.

5.1.2 *Data Storage and Recording*

For each park visitor observed, a point at the approximate location is recorded, a unique ID is given, and the observer determines the attributes according to the list above and enters the values into the database. Each change in attribute (such as permanent shift of location, or change in activity) is recorded via a new point that keeps the visitor’s original unique ID. Conceptually, the data model uses linear time that is discrete and based on the geographical entities observed, i.e. the park users. A simplified spatio-temporal entity-relationship model (Tryfona, Price et al. 2003) was implemented and is shown in Figure 5-1:

Figure 5-1: Conceptual Data Model



Source: own design

In detail, a temporal object table stores non-changing data about the individual park users (“individual” in the above figure). ID is the primary key. Additionally, coded information about age, gender, group, and notes is stored. A temporal observation table stores the event information (“event” in the above figure), i.e. start time, location (via digitized points) and type of individual activities. The database only records valid time, and the smallest temporal granularity of the temporal domain is one minute.

The data model is event-based in the sense that an entry in the temporal observation table refers to the change of an attribute (including location) in one or more of the entities. In the pre-processed state, this is still considered an object change view (Beard 2007), because no information about previous states is contained within the event information itself. The type of change has to be inferred from looking at the previous states of the object. Concerning the database implementation, the project started with a versioning/time-stamping approach, because this is the most appropriate way for recording the data. Subsequently, one can move towards both snap shot and time slice models.

5.1.3 *Types of Expected Uncertainty*

The problems concerning the terminology of uncertainty have been hinted at in section 3.4. It is necessary to define the terminology used throughout this thesis. For our project, I define the aspects of uncertainty as follows:

Inaccuracy: Errors made during the observations, concerning both spatio-temporal location as well as attributes. In other words, this would be the difference between the records in our database and a ground truth.

Incompleteness: Some of the details may not have been recorded due to a perceptual and cognitive overload on the part of the observers.

Vagueness: Personal spaces and activity footprints have both conceptually and actually vague boundaries.

5.2 Space Appropriation Analysis Methods

Following the line of thought developed in Chapter 3, I divided this section into a section on object-based (vector) analysis approaches, and one on continuous (raster) analysis approaches. The original research question two is further specified into the following two questions:

- How can one represent the area claimed by visitors for themselves, in which they feel disturbed by the activities of others?
- How can one represent the area covered (appropriated) by different activities?

Concerning possible visualization types, there is a large body of literature on static thematic maps, which I will not reiterate here. The visualization method will be addressed in the Chapter 7 on results.

5.2.1 *Object-based Vector Analysis Approaches*

There are a number of object-based analysis approaches. I briefly discuss only the most promising ones. However, all share the same problem, in that they use crisp boundaries and therefore do not represent human space appropriation adequately.

Minimum Convex Polygons: This method is used in ecological sciences for the determination of a habitat. Usually, the known space-time locations of an observed entity (herd, individual animal) are plotted on a planar space. The outer points of this point cloud are connected via convex polylines. The resulting minimum convex polygon determines the habitat. The idea in this context is its use for determining the appropriation of space by individuals, as Schmit and Killer (2004) did in a pilot study. However, research in ecological science has acknowledged the problems associated with this method, e.g. a lack of information about the intensity of space use, and outliers can seriously distort the resulting habitat (Katajisto and Moilanen 2006).

Voronoi Tessellation: A non-statistical interpolation method, it is used for a relatively simple approximation of the spatial distribution of georeferenced data samples. A Voronoi diagram of a set of points is the partition of a plane that associates a region with each point from the set. All points in that region are closer to that point than all other points. In this case, the Voronoi-Polygons could approximate the appropriation of space by park users by showing who appropriated which area by applying the polygon method.

Buffering: A straightforward method, buffering of the individual park visitors could meet the requirements of the model. Several distances for the personal spaces and activity footprints are possible, as well as unions of buffers (for group members) and intersections (to determine overlaps between groups).

5.2.2 *Field-based Raster Analysis Approaches*

The observational data will be in the form of point data. In order to use a field-based raster implementation of the model, one will therefore have to use some kind of interpolation method. Because Kernel Density Estimates have been used for the most part, they are the focus of this section.

Inverse Distance Weighting: Inverse distance weighting (IDW) is an interpolation method where values for unknown cells are estimated from given, known values (that are arbitrary in this case) in the neighboring cells; additionally, the value is an average of surrounding values, i.e. high appropriation intensity located within a group of people is not represented.

Euclidean Distance: Euclidean distances assign values to cells simple based on the distance to a source cell. For this purpose, it would have to be used inversely, i.e. the closer to a source cell, the higher the values.

Kernel Density Estimations: Kernel Density Estimations (KDE) is a well-researched spatial analysis method. Detailed information on KDE can be found in several text books and publications (Silverman 1986; Fotheringham, Brunsdon et al. 2000). It meets the model’s requirements. Concisely, KDE for point data calculates for each output grid cell the density of points around it. Conceptually, a smoothly curved surface is fitted over each point. The surface’s value is highest at the location of the point and diminishes with increasing distance. The density at each output raster cell is calculated by adding the values of all the kernel surfaces where they overlay the raster cell center:

$$\mathbf{f(x,y)} = \frac{\mathbf{1}}{\boldsymbol{nh^2}}\sum_{\boldsymbol{i=1}}^{\boldsymbol{n}} \boldsymbol{K}\left(\frac{\boldsymbol{d_i}}{\boldsymbol{h}}\right)$$

1) Kernel Density Estimation

where *f(x,y)* is the density estimate at the location *(x,y)*, d_i is the distance between location *(x,y)* and the *i*th location, *n* is the number of observations, *K* is the kernel function that determines the shape of the surface, and *h* is the bandwidth (also called smoothing parameter, or window width). The bandwidth determines the spread of the function. Larger values smooth the surface, while smaller values result in a spikier surface. A benefit to the analysis is the fact that the probability surface generated by kernel density estimations also ameliorates the problem of inaccurate and incomplete data: The closer to the center of activity (represented by the original point), the more probable and intense the park user actually uses that space. Additionally, KDE represent well that personal spaces and activity footprints have no crisp boundaries, and the intensity of space use does not decrease linearly with distance. For the determination of overlaps, map algebra functions can be used.

5.2.3 *Including the Temporal Dimension*

The model precludes any aggregated measurements or analysis of space appropriation. Since an individual's space appropriation depends on the space produced by others, while simultaneously contributing to the production of space, each moment in time is unique and different from all others. Space appropriation is a continuous process, whose length of states is infinitesimal short. As with all continuous phenomena, it needs to be broken into discrete units for analysis. I propose to use the recorded events for this. Events represent the change of at least one individual's attributes. In practice, this means location or type of activity. This includes the appearance of new individuals or the disappearance of already observed individuals. Human movement is continuous, so it needs to be broken into discrete units as well. This has to be left to the judgment of an observer, who decides when a new event is recorded because of a significantly changed location. This introduces some uncertainty and arbitrariness, which has to be minimized by careful preparation and testing.

Each recorded event requires therefore the complete recalculation of all spatial interactions (i.e. overlaps) of all personal spaces and activity footprints.

5.3 Global Analysis Methods

The global analysis at the level of public parks is more concerned with the third research question (see Chapter 1): What is the spatio-temporal distribution of observed activities, according to age, gender, or activity?

Again, the multitude of quantitative analysis methods at a researcher's disposal cannot be subject of this section. Instead, a pre-selection was made and only the relevant techniques are presented. First, I outline suitable methods for analyzing the spatial distribution, before the temporal dimension is included in the following section.

5.3.1 *Spatial Distribution of the Visitors' Activities*

First, the global distribution of visitors is of interest. Several analysis methods are well suited to analyze a global distribution of point data.

Mean Center: The mean center has as its coordinates the average of all x-coordinates and y-coordinates of all the features in the study area:

$$\bar{x} = \frac{\sum_i x_i}{n}$$

2) Mean X value of mean center

$$\bar{y} = \frac{\sum_i y_i}{n}$$

3) Mean Y value of mean center

If computed separately for different values of an attribute, the mean center can hint at different distributions, e.g. of male and female visitors.

Standard Deviational Ellipse: The Standard Deviational Ellipse (SDE, or Directional Distribution) measures the compactness of features and the general direction or orientation of the distribution. In order to measure the compactness, the standard distance in the x- and y-axis is calculated in a similar manner as the standard deviation for a set of data values. The standard distance is the average difference in distance between the features and the mean center of the distribution. In contrast to a standard distance circle, the x- and y-values are calculated separately. The mean x- or y-coordinate value is subtracted from the x- or y-coordinate value of each point, then each difference is squared, then summed, before finally the square root of the resulting value is taken:

$$SD_x = \sqrt{\frac{\sum_i (x_i - \bar{x})^2}{n}}$$

4) Standard Distance for the x-axis

$$SD_y = \sqrt{\frac{\sum_i (y_i - \bar{y})^2}{n}}$$

5) Standard Distance for the y-axis

The ellipse is centered on the mean center and rotated until the sum of the squares of the distance between the features and the axes is minimized.

Nearest Neighbor Index: The nearest neighbor index measures the observed mean distance between features and their nearest neighbors and compares this to a hypothetical random distribution’s mean distances between features and their nearest neighbors.

$$\bar{d}_o = \frac{\sum_i c_i}{n}$$

6) Observed mean distance

where $\bar{d}_o$ is the mean distance for the observed distribution of features, c_i is the distance to each feature's nearest neighbor, and n is the number of features.

$$\bar{d}_e = \frac{0.5}{\sqrt{\frac{n}{A}}}$$

7) Expected mean distance for random observation

The comparison can be based either on the difference between the observed and expected (random) distance or on a ratio of the observed distance divided by the expected distance:

$$r = \frac{\bar{d}_o}{\bar{d}_e}$$

8) Nearest Neighbor Index as ratio

If r = 1, the observed distribution can be considered random. If r < 1, the pattern is clustered, and if r > 1, the pattern is dispersed. In order to measure the significance, a Z-Score is calculated that divides the difference between observed and expected values by the standard error. The standard error measures the distribution of the mean distances around their average value.

$$Z = \frac{\bar{d}_o - \bar{d}_e}{0.26136 \Big/ \sqrt{\frac{n^2}{A}}}$$

9) Z-Score for Nearest Neighbor Index

The Z-Score determines the confidence level at which the Null-Hypotheses (random distribution) can be rejected (Mitchell 2005). Some standard values are shown in Table 5-4:

Table 5-4: Z-Scores and Corresponding Confidence Levels

Confidence Level	Z-Score
0.01	± 2.58
0.05	± 1.95
0.10	± 1.65
0.20	± 1.28

Source: Mitchell (2005), p. 65

K-Function: The K-Function is similar to the nearest neighbor index calculation in that it attempts to give a measure of the clustering of the features using the distance between them. Instead of using the distance to the nearest neighbor, it counts the number of features within a given distance around each feature, and then sums the values. The distribution is clustered if the number of features is higher than the number of an expected (random) distribution. The value is calculated at user-specified distances bands, which makes this calculation a very promising method to test the clustering at several personal distance zones.

Nearest Neighbor Hierarchical Clustering: In this method, the distance between features is used to build hierarchical clusters of discrete features. After delineating the first set of clusters, the algorithm continues to group the features into larger clusters until a user-specified threshold distance between clusters is reached. The user can also specify a minimum number of features necessary for a cluster. For a full discussion of this advanced technique, see Levine (2006).

Kernel Density Estimations: Again, KDE seem to be a promising analysis method. KDE have been used on crime data at an aggregate meso/macro scale in the search for hot spots. The observation data is very similar to crime data, where incidents usually are recorded as points that have several attributes such as type of crime, time, and many others (Kwan and Lee 2003; Levine 2006; Brunsdon, Corcoran et al. 2007).

Other spatial statistics, such as the global and local versions of **Moran's I or G-Statistics**, work best for areal data with continuous values. The observational data, however, has categorical/nominal values that are attributes of points. An arbitrary aggregation into zones would introduce the modifiable areal unit problem, and has therefore not been attempted. Using these statistical methods on the derived continuous areal values for space appropriation and potential crowding does not seem feasible at this point, since the results will have to be tested thoroughly before further analysis.

5.3.2 *Spatio-Temporal Distribution of the Recorded Data*

At this point, it is necessary to elaborate on the four different types of spatial and/or temporal interaction (compare CrimeStat Manual Chapter 9 (Levine 2007)) that arise from space-time interaction.

First, there could be no space-time interaction because the spatial clustering occurs persistently all the time. An example would be a group of marginalized beer drinkers, occupying the same table every day from morning to evening.

Second, spatial clustering could occur within specific recurring periods only, such as the use of playground infrastructure during school breaks.

Thirdly, a "real" space-time clustering could be observable, in which a number of events occur within a short period within a small area. An example would be mothers attending children, who gather close to each other in different parts of the parks, although they do not know each other beforehand.

Finally, there might be a more complex form of space-time interaction that follows patterns and causalities, which are influenced by many (yet unknown) factors.

Clearly, the first and second types are most interesting for the research project, because they represent use patterns. Type 3 could be attributed to random clustering, or rather the fact that certain activities cluster (i.e. those that are complementary or supplementary).

For temporal analysis in general, I refer to the space-time analysis tools as provided by (Levine 2007). Concerning the data available, only the Knox index is feasible.

Knox Index: It is a comparison of the relationships between incidents in terms of spatial and temporal distance. Each individual pair of events is compared. This results in N*(N-1)/2 pairs. All calculated distances are classed as either "close" or "not close", with the definition of a threshold value left to the user. A simple 2x2 matrix is produced. The number of pairs in each cell is then compared to an expected number. The difference between observed and expected number of pairs in each cell is measured with a Chi-square statistic. To account for the interdependency of the data, a Monte Carlo simulation is run. The resulting values can show when there is a significant spatial clustering, which can then in turn be examined with the statistics outlined in the previous section.

5.3.3 *Observation Sample and Neighborhood Population*

To detect exclusion or inter-site displacement, the observed composition of park visitors is compared with an expected composition, which is derived from the neighborhood population.

In order to compare the observed frequency distribution of attributes (of the park visitors) with the expected distribution (of the surrounding neighborhood), the appropriate test statistic is a Chi-Square-Test:

$$\chi^2 = \sum_{i=1}^{n} \frac{(O_i - E_i)^2}{E_i}$$

10) Chi-Square Test

where O_i is an observed frequency, and E_i is an expected frequency. The expected frequency has been determined using the data for the appropriate neighborhood for 2006 from the official statistical yearbook (Zürich 2008).

The test for goodness of fit will be done for gender and age groups, to check whether there is significant underrepresentation of any group. Thus, the null hypothesis is:

$H_{0:}$ There is no difference between the frequency distribution of gender or age groups observed and the frequency distribution of the neighborhood population.

5.4 Visualization Methods

As I have argued in the introduction, I do not agree that research can be labeled as strictly "quantitative" or "qualitative", but instead is always located in a continuum between these two. Although focusing on quantitative methods, I also employ qualitative methods in the form of visualizations. I expect two advantages from the visualization of human space appropriation. One, it provides a starting point for further statistical and spatial analysis during the exploratory phase, which could provide more insights. Second, it lowers the access barrier for practitioners in the design and management of public spaces to use our concepts for the improvement of public parks. An intuitive visualization allows practitioners to spot problems and investigate them further with qualitative observations and interviews.

5.4.1 *Suitable Visualization Methods*

I will focus on the following visualization methods for the exploratory and quantitative analysis in Chapter 7:

The symbology will have an important function. The first explorations of the data will use static, qualitative dot maps, while the aggregated global analysis will rely on area maps that might use the third dimension to display additional variables or to double encode one variable. For an in-depth analysis of the spatio-temporal data, space-time cubes seem a feasible method.

Different animations will use time as sign-vehicle for the temporal aspects. However, since every observation session will need specific analysis (global data cannot be displayed this way), the large number of animations to be created might prohibit a systematic analysis using this method. In the print version of the thesis, any animations will be presented as small multiples.

Multiple views will be used mainly in the form of small multiples. While multiple coordinated views will play a part during the exploratory phase of analysis. Small multiples will display the snapshots of spatio-temporal data, and multiple attributes of one dataset.

5.4.2 *A Simple Evaluation Framework*

In the field of visualization theory, substantial unknowns remain (compare section 3.3.3). Many limitations and problems of the new visualization techniques have just now come under scrutiny. Empirical evidence on cognitive and usability issues through evaluation is still scarce (Slocum, Blok et al. 2001; Slocum, Sluter et al. 2004). Many studies seem not to deliver what they promise, because they compare very different types of visualization techniques and content, thereby not producing useful evaluations that can serve as guidelines for the creation of effective visualizations (Tversky, Morrison et al. 2002). A ready-to-use methodology for the design of geovisualization tools in the literature does not exist. So far, the development of spatio-temporal visualization tools is still largely an empirical endeavor supported by more or less systematic evaluation (Ogao 2002; Ogao and Kraak 2002; Andrienko, Andrienko et al. 2005; Andrienko, Andrienko et al. 2005; Fabrikant 2005; Fuhrmann, Ahonen-Rainio et al. 2005; Griffin, MacEachren et al. 2006; Koua, MacEachren et al. 2006).

The possibilities that information visualizers see and implement do not necessarily represent the needs of practitioners. Andrienko, Andrienko et al. (2006) have shown that practitioners with their expert domain knowledge, where the needs are task- and data-driven, have sometimes very different requirements than visualization experts, where research is mainly technology-driven.

Two key requirements for a successful geovisualization are interactivity and cognitive adequacy. High interactivity is probably the most important development and characteristic for geovisualization (Dykes 2005). A high level of interactivity requires a high fluidity, i.e. fast response rates. Additionally, it is imperative to understand the process of human visual perception and cognition. An information overload that exceeds cognitive and perceptual limits causes small changes to be missed and is a common problem especially in animated visualizations (Tversky, Morrison et al. 2002; Harrower and Fabrikant 2007). The chosen media type should correspond to the purpose of the visualization (thinking or communication) and resulting functions are derived from cognitive processes involved (Dransch 2000).

The evaluation framework combines this with two basic purposes of visualizations: Knowledge production and knowledge dissemination (compare Chapter 3).

I postulate that knowledge production through scientific visualization is mainly dependent on the factor of interactivity. Only if the researcher or practitioner can look at a phenomenon from as many perspectives and in as many ways as possible, can he or she draw tentative conclusions and decide on further roads of investigation.

Knowledge dissemination through visualization on the other hand depends on established cartographic principles of symbolization, classification, and cartographic design. According to MacEachren (1995), a hypothesis could be that information displays will be most effective when the display’s logical schema matches the viewer’s knowledge schema. I modify this hypothesis by postulating that the efficiency of knowledge dissemination depends on the level of complexity and abstraction.

In short, if a visualization technique has a high level of interaction, then it might be appealing to researchers trying to discover new knowledge. If a visualization technique has a low level of abstraction and matches common knowledge schemas, it might be especially suited for knowledge dissemination. Each produced visualization is evaluated within this framework. For a discussion of their suitability for specific purposes, I refer to Chapter 8.

5.5 Summary of Chapter 5

I argue that for the detection of any processes of exclusion or displacement, one first needs to know the actual usage of space. This actual usage and appropriation of space can be captured with data from observations that recorded age, gender, and activities as primary components. The data is event-based: Individual activities of park users are recorded as points with the relevant attributes. The observations are planned systematically for three parks over the span of three years to get representative results.

The model introduced in Chapter 4 will be implemented with both discrete object-based and continuous field-based methods. Most promising approaches are buffers and kernel density estimates.

In addition to the detailed analysis of space appropriation, the global distribution of visitors and their activities is subject to analysis, in order to detect processes of exclusion and displacement.

Finally, the visualizations will rely mostly on symbology, and will be evaluated in a simple framework, which is based on the level of interactivity and complexity.

PART IV: CASE STUDY

6 Zurich Case Study: Observations and Data Processing

In this chapter, I will first describe along which criteria the parks were selected, before giving a short overview of them. Then I proceed to show how the observational data actually was recorded, before describing the steps necessary for preparing and handling the data prior to analysis. In the final section, the quality of the data and its inherent uncertainty are discussed.

6.1 The Case Study Public Parks

The research project had the objective of observing three parks over the course of three years (2005 to 2007), although limited resources prohibited observations of all parks in all years.

6.1.1 *Criteria for the Selection of Parks*

The criteria for the selection of parks depended on both constraints and research objectives. Four main criteria influenced the decision:

1. Catchment area: The quality of public parks has its greatest impact on the level of neighborhoods, where they influence the daily quality of life. Therefore, the research project actually aims for a small catchment area. We use the same definition for catchment area as the public administration in Zurich, which is approximately 400 Meters distance (GrünStadtZürich 2006). Mostly the local population should frequent the park, and it should not serve a touristic purpose, be a landmark, or regionally attractive because of special infrastructure.
2. Infrastructure: In order to observe a greater variety of activities, the park should provide the necessary infrastructure in the form of open grass areas, benches, tables, playgrounds, access to water, and other.
3. Visibility: The method of direct data capture through observations imposes this constraint. In order to keep the error through incompleteness at a minimum, the whole area of the park should be visible from two or three vantage points, so that two or three observers can overlook the whole park.
4. Size: The constraint imposed by the small number of observers means that not too many park visitors should be in the park at the same time. Depending on the level

of activity, about twenty park visitors were expected to be the maximum for each observer, in order to keep uncertainty through inaccuracy and incompleteness within acceptable limits.

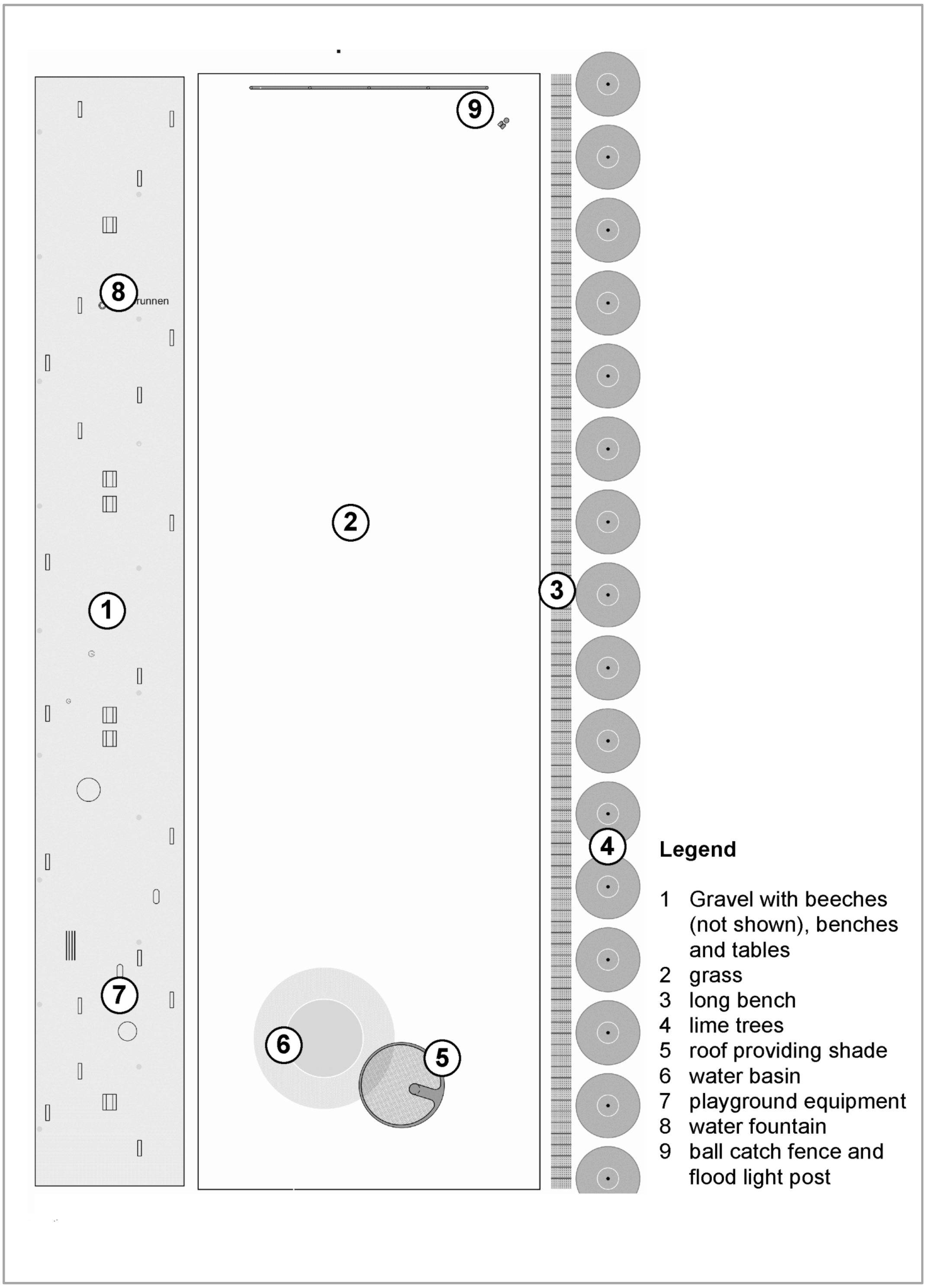
The three parks chosen are compromises meeting the criteria to a varying degree, as the next section shows.

6.1.2 *Description of Case Study Parks*

The **Wahlenpark** is an example for a recently constructed park in a completely rebuilt and converted new city quarter. On over 60 ha of formerly industrialized urban periphery, housing for over 5,000 people and work for 12,000 was planned. Today, more than half of it has been realized, with the remaining on the way. A tenth of the area was reserved for public green spaces. Today, there are five parks in total, giving the neighborhood one of the best furnishing of public park spaces of all of Zurich's neighborhoods.

The Wahlenpark was designed as multifunctional park/sports recreation space, not only for the local population in general, but also specifically for a new adjacent school. The western strip (see Figure 6-1) has benches, tables, playground equipment and trees. In the winter of 2007/2008 (after the observations), a public toilet has been installed in its lower half. At the eastern edge, there is a long, low bench and adjoining line of trees. The large open space in the center was designed for use with the school. At the upper part, there is a large fence for catching balls, with a high projection light pole creating a stadium atmosphere. At the lower end, there is a water pool with a small roof providing some shade. The whole park was under observation.

Figure 6-1: Map of Wahlenpark

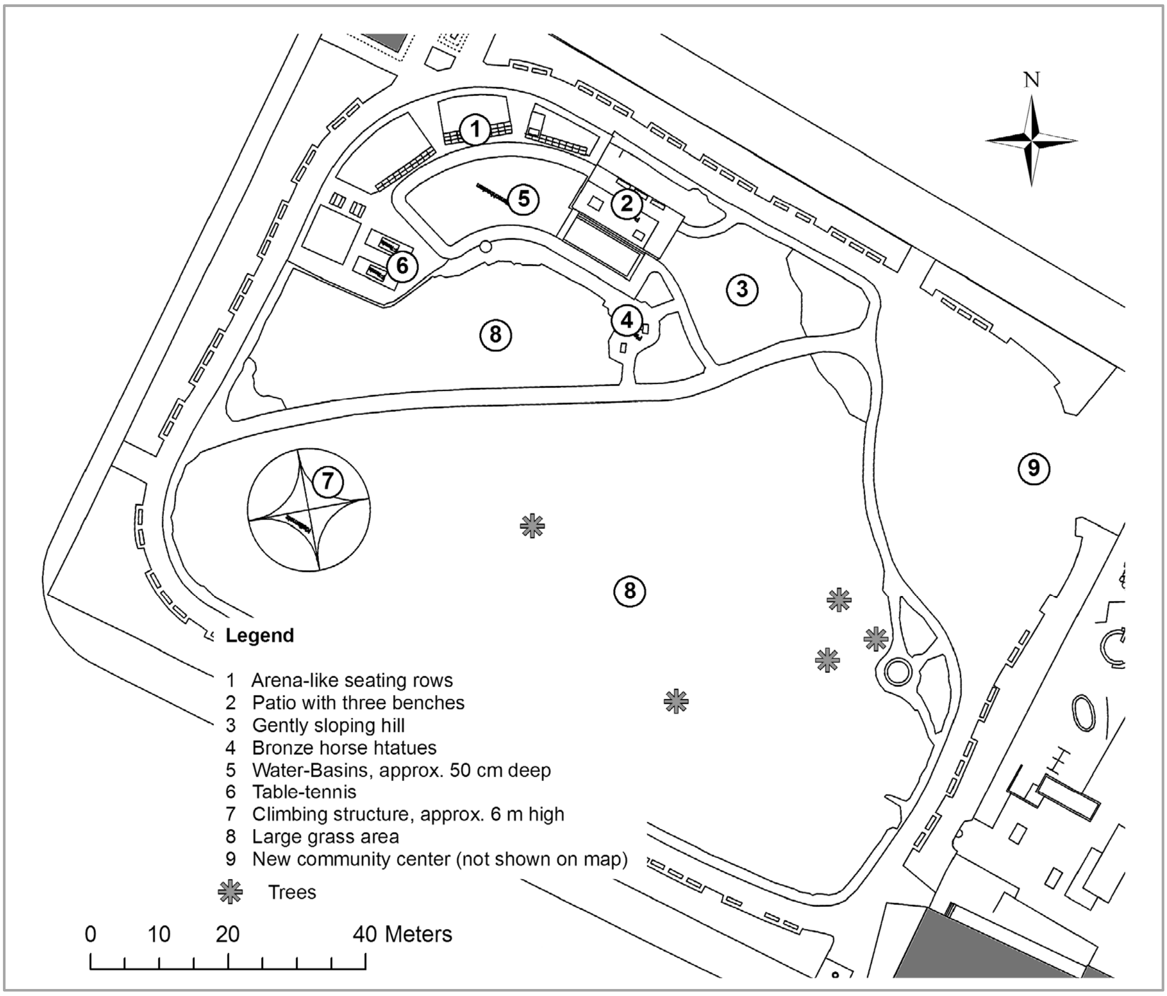


Source: GrünStadtZürich, edited by Timpf, Sabine and Ostermann, Frank

The **Bäckeranlage** is an example for an older, institutionalized park in a central, mid- to lower income multi-ethnic neighborhood (42% non-Swiss citizens, Zürich Statistical Yearbook 2008). However, there are signs of an on-going gentrification process. The

Bäckeranlage is one the rare green spaces in that neighborhood. It is surrounded by traffic-intense streets, but shielded on all sides by hedges and trees.

Figure 6-2: Map of Bäckeranlage



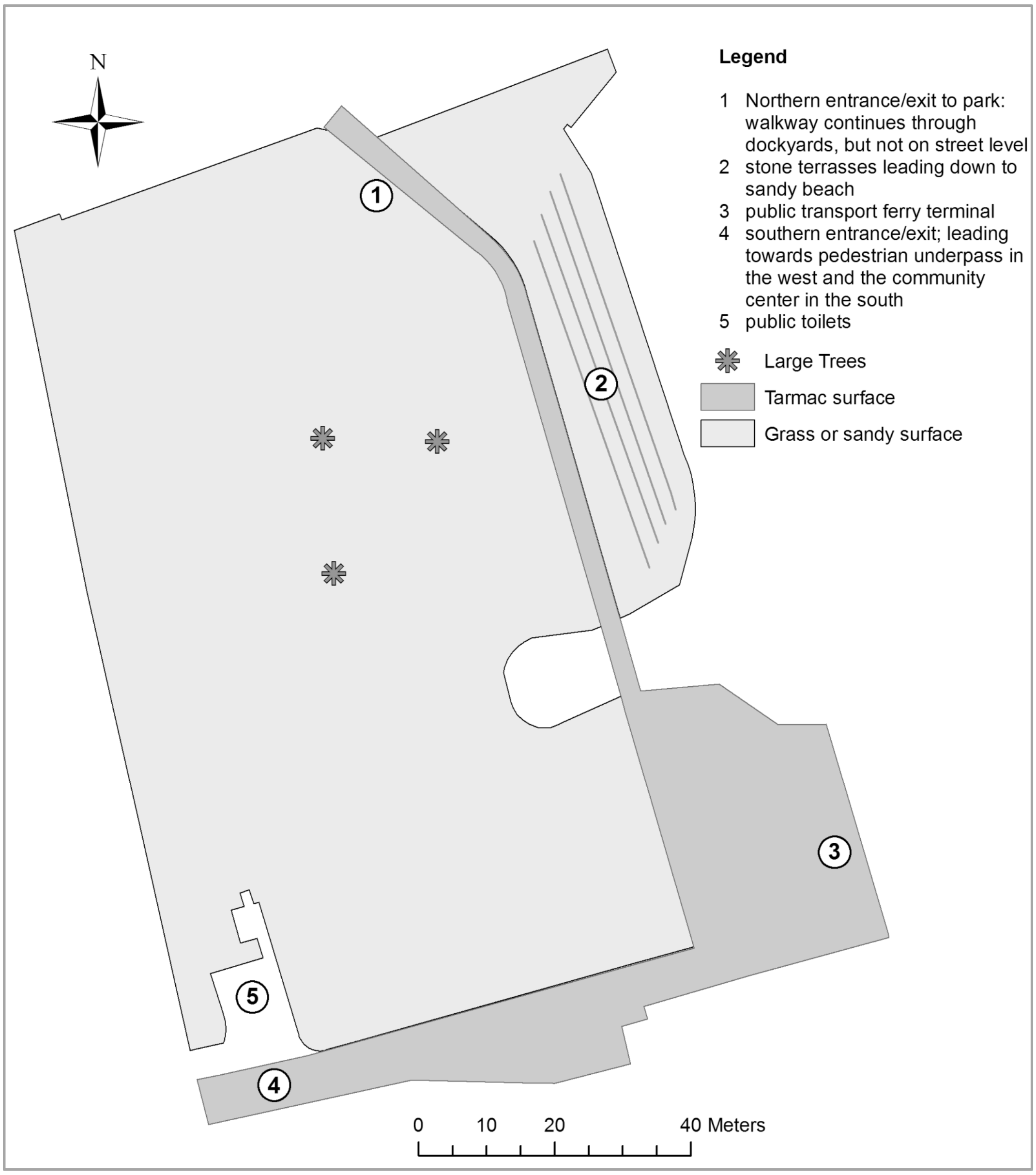
Source: GrünStadtZürich; edited by Timpf, Sabine and Ostermann, Frank

The Bäckeranlage (see Figure 6-2) was originally planned as garden-type park and opened in 1900. It underwent several renovations and restorations, the last one around 2000 in order to contain an emerging open drug scene. In 2004, a new community center was built.

The park is meant to be a garden to be lived in and experienced. There is a diverse infrastructure available, such as water basins, benches surrounding the central area, games and a small mound overlooking the open areas. In the northwestern corner (not shown on the map) are also public toilets. Only the areas 1-8 were observed, because the remaining areas were not visible enough, or proved too difficult to record (too much activity on a limited area).

The **Savera-Areal** (Figure 6-3) is in a middle- to higher-income, heterogeneous neighborhood at the periphery of the inner city at the lakeshore. The planning was initiated by a public proposal of the local neighborhood council.

Figure 6-3: Map of Savera-Areal



Source: GrünStadtZürich, edited by Timpf, Sabine and Ostermann, Frank

Its design was supposed to be simple and naturalistic, with no prominent infrastructure and mostly open space, dotted by a few trees. The park was handed over to the public in spring 1989. In the winter of 2004/2005, the lakeshore had to be renewed because of erosion. The current design consists of low stone benches that descend towards the water, becoming a narrow stretch of coarse sand beach. In the southwestern corner, a public toilet is located. Directly adjacent to the park at the southern end is a community center, providing a kiosk, volleyball field, and playgrounds. At the western and northern side are a large car sales and dockyards, respectively, although hidden behind large trees. Nevertheless, access to the Savera-Areal is limited to a walkway skirting the dockyards, a subterranean passage near the car sales property, and a narrow path along the lakeshore southwards. Although the whole park was observed, area 2 was not observed systematically with the detailed method for the same reasons as in the Bäckeranlage, i.e. too much activity on a small area.

All parks are relatively small, and easily observable. The Savera-Areal is the least local of all the parks, because of its location at the waterfront close to a community center. It also offers the least diversity in infrastructure. The Bäckeranlage has both, a community center and diverse infrastructure. Still, it is visited mostly by the local population, because of its inner-city location away from any tourist attractions or landmarks (such as the lake). The Wahlenpark scores high in all four criteria.

6.2 Realizing the Observations

First, the setup and procedure for the intended observations are presented, before an alternative aggregated observation method is explained that had to be developed ad-hoc.

6.2.1 *Pilot Studies*

A pilot study was initiated by Schmidt and Killer (2004), who began observing social processes in a small park and visualize and analyze them with a GIS. The focus was placed on differences in gender and age, while activities were not recorded.

During the exploratory phase of this research project, a more systematic observation of the Wahlenpark was conducted in the summer of 2005. The aim was to get to know the field and to reveal the first problems about what and how could be observed. Although the data of this observation is used in the analysis and is part of the research project, it was recorded before the actual work on this dissertation began. It can be considered an advanced case study or pilot project. The Wahlenpark was observed on 14 days during the month of June. Five sessions were conducted in a first, exploratory phase, and nine sessions in a second, more structured phase, all of them for three hours from 5 pm to 8 pm. The weather was generally warm and dry. For the list of dates during the pilot phase, see the following Table 6-1:

Table 6-1: Observation Sessions Wahlenpark 2005

Date	Day
16.06.2005	Thursday
17.06.2005	Friday
18.06.2005	Saturday
19.06.2005	Sunday
22.06.2005	Wednesday
23.06.2005	Thursday
25.06.2005	Saturday
27.06.2005	Monday

Source: the author

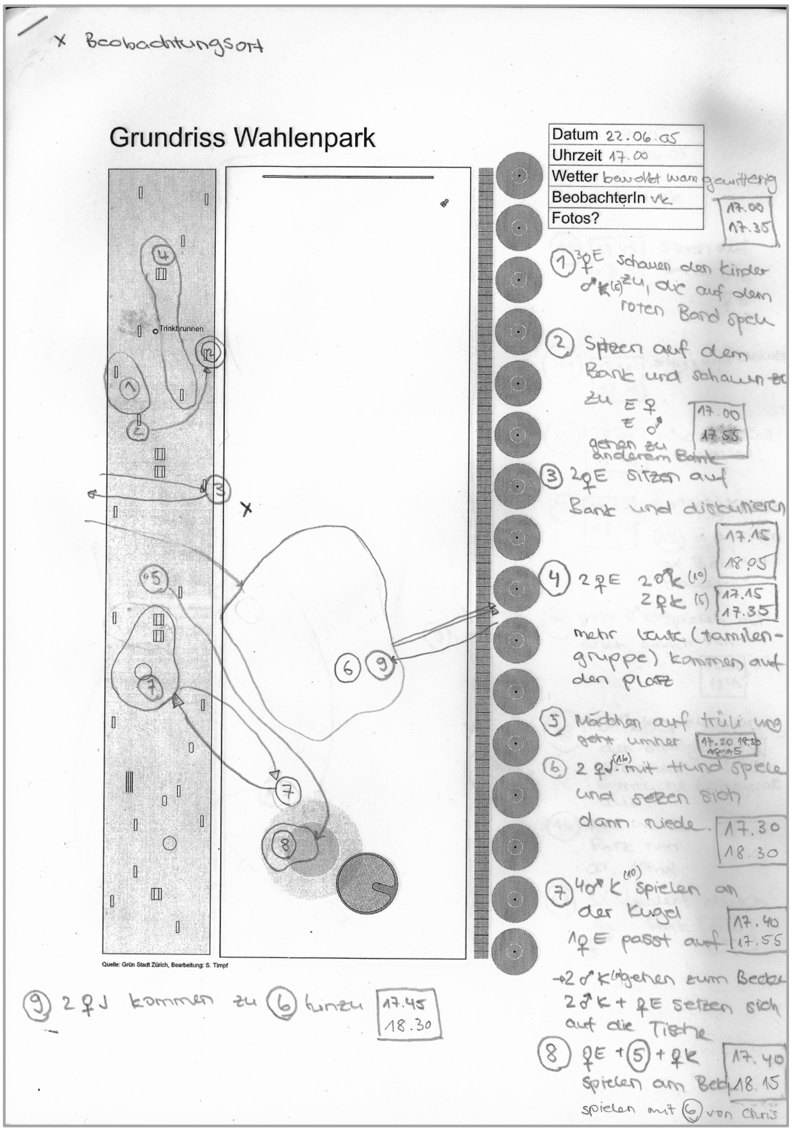
The recording method was drawing with pen and paper. Printouts of the park layout were distributed to the observers, who then recorded gender and approximate age group of all visitors, adding notes for their activities. No classes for activities had yet been determined, so as not to exclude any types. The observers were expected to be free in their recording. The data records were later digitized (see section on Data Preparation and Handling, for an example see Figure 6-4).

Valuable feedback from the observers included the following items:

- The observation time matrix was not representative enough
- The guidelines for classification needed to be more systematic and specific in order to increase intercoder reliability.
- The detailed spatio-temporal location of movement-intense activities was almost impossible to record.
- There were not many movements in the park, so trajectories are either not suitable or not possible.
- When visitors are clustered, the group affinity is difficult to ascertain.
- The maximum number of park users per observer was around 15.

I addressed these suggestions where possible, as the following section shows in detail.

Figure 6-4: Scan of Exemplary Pen and Paper Data Record



Source: Wahlenpark observation team 2005, scan by the author

6.2.2 *Detailed Observation Method*

In order to address the requirements of systematic planning and repeated evaluation (see section 5.1) the following measures were taken:

The project team decided to follow the raster developed by the pilot study, i.e. several observation periods distributed among weekdays and weekends, as well as midday, afternoon and early evening times. Taking up the suggestions from the pilot study, the team decided to use two-hour observation slots, starting at 12 pm, 2 pm, 4 pm and 6 pm. Fourteen observations slots per park were planned, with the aim of distributing them as evenly as possible among time and days of week. Some adjustments had to be made due to weather: The team decided to exclude days with rain, as there is expected to be much less use of public parks during bad weather.

Prior to the observations, the team tested the intercoder reliability and error by crosschecking and validating with redundant data.

The project team also produced detailed guidelines for the recording procedure and classification, including hierarchy for categories. In case of a frequent change between activities or simultaneous activities like talking and eating, a twofold strategy was employed: First, a distinction between primary and secondary activity could be recorded. Second a hierarchical approach ensures that the more specific or more space-consuming activities (e.g. gaming or ball games, respectively) are recorded instead of the more generic ones (such as talking).

However, the pen and paper method clearly is at odds with many of the requirements. Additionally, the later digitization adds problems of uncertainty due to misinterpretations on the part of the digitizer.

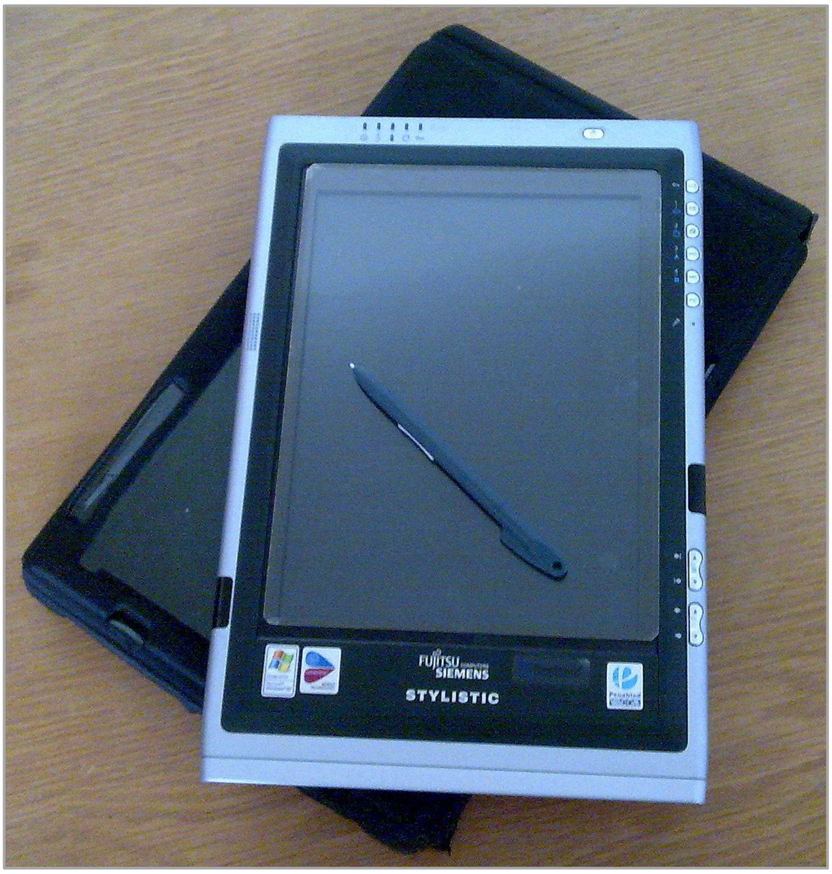
Mainly for this reason, I decided to employ a mobile GIS solution that allows for direct, coded input of the observational data, reducing thereby ambiguity from the start. A pretest with the observers ensured familiarity with the tools and intercoder-reliability. The following Figure 6-5 shows one of the TabletPCs that were used for the observations. On-site digitization was accomplished using the pen functionality under Windows XP Tablet Edition running ArcGIS 9.2.

In order to facilitate the digitization of event points and the entering of attribute values, several measures were taken:

- Pre-coded values that could be selected from a drop-down list
- Symbolization to tell different event points apart
- Combination of all relevant program functions in a customized GUI.

Figure 6-6 below shows a typical screenshot during data capture in the Savera-Areal. Three newly digitized events are selected, and an activity type is about to be chosen.

Figure 6-5: TabletPC used for Observations



Source: the author

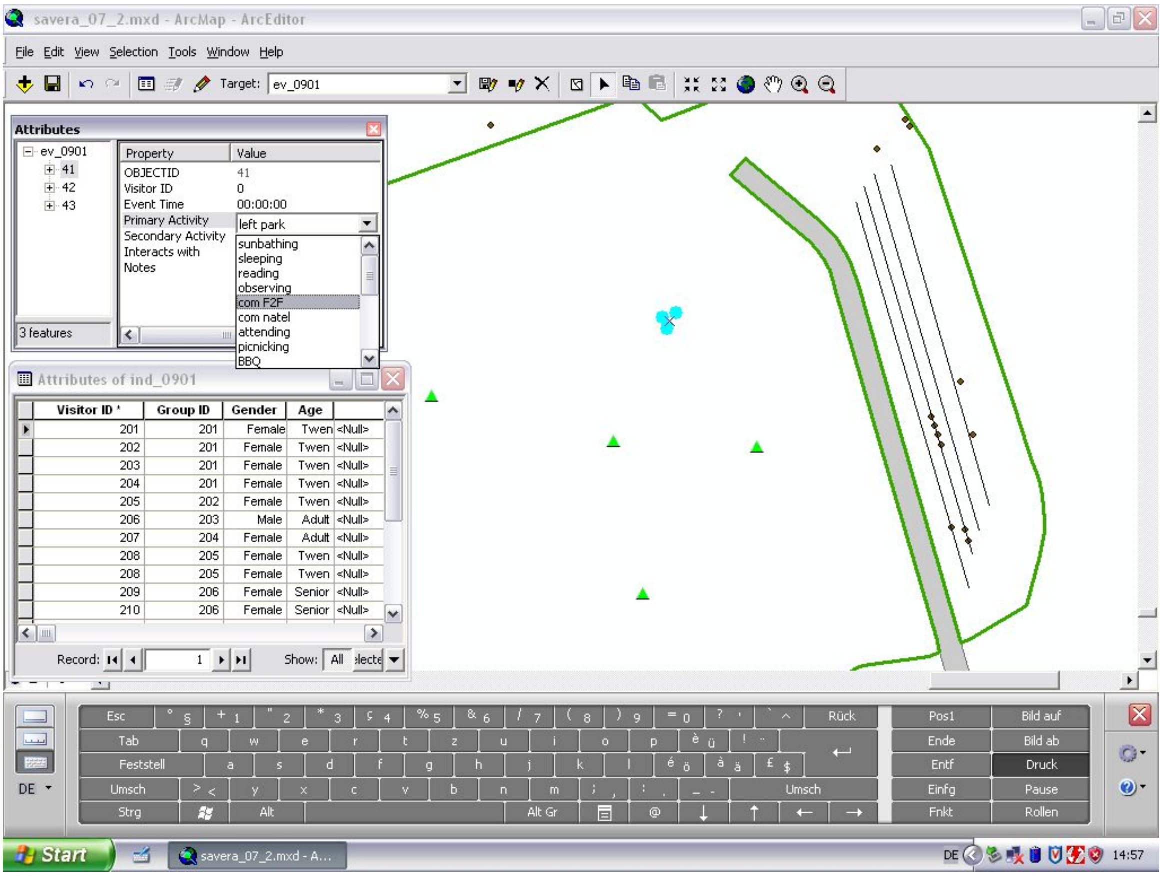
In addition to gender, age, activity, and group affiliation (see section 5.1), the observers recorded the following information:

Spatial location: Since it proved impossible to record the precise space-time location of all visitors at all times, the team did not record people's trajectories, instead recording the approximate center of activity for activities involving lots of movement. If a distinctive relocation of the center of activity of a park visitor occurred, a new location with the same ID was recorded. In very specific cases, a polygon could be drawn to delimit the boundaries of the space used. People just crossing the park without using it were not recorded.

Temporal location: Each record is assigned a start time with a resolution of one minute.

Notes: To allow for the recording of specific causalities and other qualitative information, notes assigned to events, people and places were possible.

Figure 6-6: GUI of Detailed Recording



Source: the author

6.2.3 *Aggregated Observation Method*

During the observations, one serious problem occurred: Occasionally, the number of visitors proved to be too high for the planned, detailed observations. Improving the GUI and increasing experience of the observers could ameliorate this problem to a certain extent. The limiting factor is the number of groups and individuals a single observer can keep an eye on. Two hypothetical solutions were not feasible:

1. Video recording: Inquiry at the municipal data privacy official showed that the legal requirements could not be met. While adults could show implicit consent with video recording if a sufficient advertisement was made at the entrances of the park, an explicit written consent of the legal guardians for minors is required and in practice impossible to get.
2. More observers: The limited resources of the project did not allow for more than three observers.

In both cases, the consequences of video recording or large numbers of observers on the behavior of the park visitors led to further doubts about these two measures.

In order to fulfill the project requirement of a certain number of complete observations, a second, less detailed observation method that nonetheless was compatible to the established one had to be developed. The ad-hoc nature of the method development had to reduce on detail in every aspect: spatial, temporal, attribute.

Spatial and Temporal Aggregation: Each park was divided into several meaningful regions. In most cases, the park infrastructure provided the areal boundaries, such as a grassy open area divided by a tarmac walkway, or sitting areas with a water pool in between. Sometimes, divisions that are more arbitrary were necessary such as plotting a perpendicular line from a base through a freestanding tree in the midst of an open area. The observation team had to forego the event-based recording and opt for a snapshot approach: Every fifteen minutes, the observers counted the number of visitors in each area.

Attribute Detail: While it was not possible to reduce the number of gender classes, the age groups were reduced to three: Children, Adults, and Seniors. No activities were recorded, except if some specific space-consuming activity was carried out by a larger number of park visitors. In such a case, the observers drew shapes showing the approximate extent of the activity footprint and recorded the age and gender of the participation visitors. This qualitative recording allowed the capture of significant events.

The rationale behind this approach is that it is possible to aggregate the detailed data to level that makes it comparable and easy to merge with the aggregate data. For more on this, see section 6.5.

6.2.4 *Observation Procedure*

First, the observers chose a suitable vantage point and located it on the map. Selection criteria included a good line of sight to all parts of the observation area. At the same time, the location should have as little exposure as possible, so that a potential observer influence was minimized. If park visitors showed signs of discomfort due to the presence of the observers, they were to choose another location. If possible, the same locations should be used throughout all observations. In case of questions targeted at the observers, a prepared handout was shown explaining the main items of the observation: University affiliation, research objectives and guarantee of anonymity. In case of further questions, the visitor was asked to contact the university later, because otherwise the current observation would have been rendered less useful because of incomplete data.

The observers then divided the park area among them. Ambiguous situations (e.g. visitors moving back and forth between those areas) were discussed via mobile phone if the observers were not within direct talking distance. Any other unclear items were discussed and decided upon in a similar manner. Once the observations had started, the observers kept an eye on everything that happened in the park. If at a certain point the cognitive limits were reached, observing switched from detailed to aggregated method.

In general, the observations were conducted without major problems. Interest in the observers was very low, with only three interactions (i.e. questions posed) from the observed park visitors, among them two children. One could take this as an indication of the low impact the observers had on the life in the park. In all three cases, reactions were positive.

6.3 Data Post-Processing

Several steps were necessary to prepare the raw data for analysis and visualization. These were mainly transformations, reclassifications, and merging of datasets. Prior to these, I checked the data for syntactical errors, such as multiple entries, missing entries, out-of-range values (although using coded values for the attributes, not all value ranges could be predefined). Erroneous data was examined for hints for correct values, e.g. a clearly wrong group ID could be reconstructed if the data tuple had the same event time as other spatially close tuples, thus suggesting an affiliation to that group. If no reconstruction was possible, the data tuple was eliminated. Less than 1 % of the data had errors that could not be corrected. The same procedure was used for errors that I became aware of during transformations and reclassifications.

6.3.1 *Transformations*

I reformatted the start time field in several ways, because many tools only allow a certain time format to be loaded, manipulated and displayed.

Next, an end time for events was calculated by looking up subsequent entries of the same individual park visitor. The calculation of an end time, in turn, allowed the calculation of activity durations for those activities completely observed, i.e. excluding those that had already begun when the observation started and those that continued after the observation had ended. For the scripts employed, see the Appendix.

Finally, the temporal object table was hard-joined to the temporal observation table because several analysis tools proved to be unable to deal with soft-joined data.

6.3.2 *Reclassifications*

Several reclassifications were necessary. These included:

Age: The formerly six classes were reduced to four. Infants were reclassified as children, because there were only comparatively few (<1%). Young and senior adults were reclassified as adults, because the distinction proved to be too vague and error prone.

Activities: I decided to drop the information about multiple activities, which was rarely used. In the case of primary and secondary activities, a hierarchical approach chose the activity with the greatest impact on its surroundings (i.e. Dynamic over Static) and assigned it as the new primary activity.

The final data looks like the following Table 6-2 (redundantly formatted time fields omitted for ease of view). The columns, from left to right, are the date, coded weekday, observation time slot, date and event start time combined, start time, computed end time, computed duration, coded activity, coded gender, coded age, ID of park visitor, and group affiliation:

Table 6-2: Raw Data Format

date	day	slot	datetime	start	end	dur_num	activity	gender	age	ID	GID
20060831	4	2	20060831140000	140000	160000	120	2	1	3	1	101
20060831	4	2	20060831145555	145555	160000	64	0	1	3	2	102
20060831	4	2	20060831141010	141010	145555	45	1	1	3	3	102
20060831	4	2	20060831143737	143737	155050	73	5	1	3	4	103
20060831	4	2	20060831155050	155050	160000	10	2	1	3	5	103
20060831	4	2	20060831141515	141515	143737	22	2	1	3	6	103
20060831	4	2	20060831141515	141515	144040	25	2	2	3	7	103
20060831	4	2	20060831144040	144040	145757	17	5	2	3	8	103
20060831	4	2	20060831145757	145757	154040	43	2	2	3	9	103
20060831	4	2	20060831154040	154040	160000	20	5	2	3	10	103

Source: the author

6.3.3 *Merging*

The merging of the individual datasets was easily done by simply merging the individual data tables. The primary key is now a combination of date and ID. The aggregated data was also merged. In order to obtain complete data sets for the observations periods, the detailed data had to be merged with the aggregated data. This phase involved the following steps:

1. Reclassify Age again (merge Children and Teenager)
2. Identify the region in which each event occurs
3. Count all the events in the region for each snapshot time according to age/gender group
4. Merge this data with the existing aggregated data

Prerequisite for this method is that the duration of stay does not differ significantly between males and females. If that would be the case, those with longer average duration of stay would count more often towards the total. In order to determine the correct statistical method for testing the frequency distribution, the data has first to be tested for normal distribution. A Kolmogorov-Smirnov-Test showed the following results (Table 6-3; only those events were selected where the start and end times were known):

H_0: The frequency distribution of the values of the variable "Duration" is normal.

Table 6-3: Results of Kolmogorov-Smirnov-Test for Duration

One-Sample Kolmogorov-Smirnov Test		
Variable Tested		Duration
Number of events (only those with a definitely observed start and end)		2610
Parameters of Data if normally distributed	Mean	19.71
	Std. Deviation	21.076
Most Extreme Differences	Absolute	.189
	Positive	.189
	Negative	-.175
Kolmogorov-Smirnov Z Value		9.680
Significance level (2-tailed)		.000

Thus, at a significance level of $p < 0.001$, the null hypothesis can be rejected. I therefore assume that the variable "Duration" is not normally distributed.

In this case, a rank-sum test like Mann-Whitney U test is suitable and was performed to check with a for goodness of fit (see Table 6-4).

H_0: The frequency distribution of the variable "Duration" does not differ between male and female visitors.

Table 6-4: Results of Mann-Whitney U Test for Duration

Rank Sum Test Statistics	
Grouping variable: Gender	Tested Variable: Duration
Mann-Whitney U result	774378.000
Wilcoxon W result	1497381.000
Z score	-.218
Significance level (2-tailed)	.827

At a significance level of 0.827, the null hypothesis would be falsely rejected and the durations for male and female visitors were in fact not significantly different. I considered this probability high enough to continue with the merging of the data. For a detailed listing of the merge script, see the Appendix.

The data had now been merged to create a single data set. For an overview of descriptive statistics, see the next section.

6.4 Overview of the Recorded Data

6.4.1 *Timetables of Observation Sessions*

The following tables 6-5 through 6-8 show the observation sessions. Note that in the Savera-Areal, the team decided to observe on fewer days but with double shifts, in order to record longer continuing use and get additional information on the durations of activities. The Type denotes whether the observations are detailed, aggregate, or hybrid. The latter is characterized by a switch from detailed to aggregate (when the cognitive limits of the observers were exceeded), or a combined simultaneous detailed and aggregate recording.

Table 6-5: Observation Sessions Wahlenpark 2006

Date	Day	12-14	14-16	16-18	18-20	Type
17.06.	Saturday	x				detailed
19.06.	Monday				x	detailed
20.06.	Tuesday		x			detailed
21.06.	Wednesday			x		detailed
22.06.	Thursday				x	detailed
23.06.	Friday	x				detailed
24.06.	Saturday		x			detailed
30.06.	Friday		x			detailed
03.07.	Monday				x	detailed
04.07.	Tuesday			x		detailed
05.07.	Wednesday			x		detailed
08.07.	Saturday			x		detailed
08.07.	Saturday				x	detailed
11.07.	Tuesday	x				detailed

Source: the author

The Wahlenpark was observed in 2006 for 28 hours in total, distributed over 14 days.

Table 6-6: Observation Sessions Bäckeranlage 2006

Date	Day	12-14	14-16	16-18	18-20	Type
31.08.	Thursday		x			detailed
01.09.	Friday	x				detailed
04.09.	Monday			x		detailed
05.09.	Tuesday				x	detailed
07.09.	Thursday		x			detailed
08.09.	Friday		x			detailed
09.09.	Saturday	x				detailed
11.09.	Monday			x		detailed
12.09.	Tuesday	x				detailed
22.09.	Friday				x	detailed
09.10.	Monday			x		detailed

Source: the author

The Bäckeranlage was observed in 2006 for 22 hours in total, distributed over 11 days. However, the data from the Bäckeranlage 2006 is only partial. This is due to short-term illness of observers, who could not be replaced in time. Therefore, the author decided to exclude that dataset from the statistical analysis completely.

Table 6-7: Observation Sessions Bäckeranlage 2007

Date	Day	12-14	14-16	16-18	18-20	Type
16.04.	Monday					testing
17.04.	Tuesday					testing
18.04.	Wednesday		x			detailed
19.04.	Thursday				x	detailed
21.04.	Saturday	x				hybrid
22.04.	Sunday		x			hybrid
23.04.	Monday				x	aggregate
25.04.	Wednesday			x		hybrid
26.04.	Thursday				x	hybrid
28.04.	Saturday			x		hybrid
13.05.	Sunday			x		aggregate
18.05.	Friday	x				detailed
24.05.	Thursday	x	x			hybrid
25.05.	Friday			x		aggregate
30.05.	Wednesday				x	hybrid

Source: the author

All areas except 9 (see Figure 6-2) of the Bäckeranlage were observed in 2007 for 28 hours on 14 days, thereof 12 hours detailed on 10 days.

Table 6-8: Observation Sessions Savera-Areal 2007

Date	Day	12-14	14-16	16-18	18-20	Type
05.06.	Tuesday		x	x		hybrid
06.06.	Wednesday			x	x	hybrid
14.06.	Thursday			x	x	aggregate
16.06.	Saturday		x	x		hybrid
20.06.	Wednesday	x	x			hybrid
01.07.	Sunday	x	x			aggregate
03.09.	Wednesday	x				detailed

Source: the author

The whole Savera-Areal was observed for 28 hours on 7 days, thereof 16 hours of detailed observations on 5 days.

6.4.2 *Overview of Detailed Data*

The following two tables give an overview of the detailed observation data, with Table 6-9 showing the gender distribution, and Table 6-10 showing the age of observed visitors. The difference in total observed visitors in the two tables is due to the exclusion of the "unknown" gender group in Table 6-9:

Table 6-9: Gender Overview of Visitors Counted

Gender	Season					
	Bäckeranlage 2006	Bäckeranlage 2007	Savera-Areal 2007	Wahlenpark 2005	Wahlenpark 2006	Total
Male	418	377	132	301	315	1543
Female	402	379	104	307	285	1477
Season total	820	756	236	608	600	3020

Source: the author

Table 6-10: Age Overview of Visitors Counted

Age group	Season					
	Bäckeranlage 2006	Bäckeranlage 2007	Savera-Areal 2007	Wahlenpark 2005	Wahlenpark 2006	Total
Children	147	158	28	235	197	765
Teenager	24	43	13	103	133	316
Adults	642	586	194	320	264	2006
Seniors	29	22	9	0	11	71
Season total	842	809	244	658	605	3158

Source: the author

6.4.3 *Uncertainty and Representativity of the Data*

The spatial **inaccuracy** varies over the observed area. Generally, the farther away from an observer and a landmark feature (such as walkway, fountain, or tree), the greater is the positional inaccuracy. Under optimal conditions, we determined a spatial inaccuracy of less than one meter. The temporal inaccuracy is about one minute, i.e. an event may have a lag of one minute. In times of high activity levels, the inaccuracy is slightly higher. The spatio-temporal inaccuracy is also related to the type of activity pursued, since the recording method did not allow the capture of all space-time locations for movement-intense activities. To account for this in the model implementation, I have used probabilistic kernel density estimations with parameters controlled by the type of activity (see section 5.2.2). Concerning attribute inaccuracy, a careful choice of attribute categories enabled a high accuracy. Exceptions include the age categories of young and senior adults, which were later merged for that reason.

Concerning **incompleteness**, only minor details were omitted during busy periods. This fact was established through notes of the observers and careful debriefing.

The **vagueness** of the boundaries of the activity footprints and the personal spaces might best be represented by the use of a continuous distance function and the transformation of the discrete object data into a continuous field data model.

It is important to note that the data is not representative at a finer temporal granularity. To that end, many more observations sessions would be necessary. At the level of observations seasons one can be confident enough that the data is sufficiently representative for a statistical analysis.

6.5 Summary of Chapter 6

The parks to be observed in the case study were selected for their function in the city context as neighborhood parks, and their suitability for observations. This included characteristics such as size and visibility. The observations were realized over a period of three years, including a pilot study. A new, digital observation method was developed. In addition to the detailed observation method, circumstances forced the employment of a more aggregated and less detailed method to capture all visitors of the Bäckeranlage and the Savera-Areal during busy days. The data underwent several transformations, such as calculation of new attributes (duration of stay), a reclassification of activities and age categories, and finally a merger of all datasets. The data is representative at a larger scale. The uncertainty introduced by the observations was acknowledged, and the quality of the data judged sufficient for analysis.

7 Zurich Case Study: Results

This chapter addresses mainly the second and third research questions (see section 1.3), restated here:

- Which methods are suitable for modeling space appropriation, analyzing the observation data and visualizing the results?
- What is the spatio-temporal distribution of observed park visitors, and does the resulting pattern of space appropriation indicate processes of exclusion and domination?

While Chapter 5 has already dealt with the methods, it is necessary to evaluate their suitability here, which is possible only during and after the actual analysis. The second focus in this Chapter lies on the analysis of the park use and space appropriation itself, and the results obtained. It is important to note that a systematic analysis of park use has been done only at an aggregate level. The analysis of space appropriation on the disaggregate micro level would have required the computation for and systematic interpretation of each single observation session, which proved outside the scope of this work. Instead, I implemented the model on space appropriation exemplary only for especially promising (i.e. potentially crowded) datasets.

An exploratory analysis helped to discover such datasets and to generate additional hypotheses based on the observed data. Then, the model of space appropriation was implemented in two different approaches, before the aggregated analysis results are presented.

A note on software tools: As mentioned in Chapter 3, there is a strong trend towards closed or proof-of-concept tools. Instead of continuing in that direction, the goal here is to test and develop a system of visualization methods for the data that is transferable to and operable within other projects with a minimum amount of work. Thus, I decided to build on the capabilities of common, off-the-shelf GIS packages. In detail, the analysis relied mainly on ArcGIS 9.2. Where necessary, I expanded its analytical capabilities with scripting (Python, Visual Basic for Applications). A multitude of other tools has been tested and was used occasionally when deemed suitable.

7.1 Exploratory Data Analysis

The kind of data captured for this study has not been collected before. The literature review on human space appropriation and space use in the Chapter 2 gives a few hints at what might be expected. However, it is necessary to acquire first an overview of the data and to develop additional hypotheses. This is the objective of the exploratory data analysis. I attempted to discover what might be worth of further investigation and analysis by visually exploring the data.

The basic tenets of exploratory visual analysis, i.e. high interactivity with multiple linked views and brushing, were applied where possible. Other exploratory techniques like box plots, histograms, or parallel coordinate plots were only of limited use. This was mainly due to the nominal scale of the recorded variables (gender, age groups, and activity types).

In order to detect general trends and patterns, the data was first aggregated into the observation seasons, i.e. Wahlenpark 2005, Wahlenpark 2006, Bäckeranlage 2007, and Savera-Areal 2007 (compare section 6.3.3). This aggregation also deemed also necessary because the representativity of the data decreases with finer temporal granularity.

7.1.1 *Exploring the General Attribute Distribution*

I begin the analysis with the detailed individual data. The average group size of all observation seasons was 2.4 park visitors, with the Wahlenpark having slightly higher group sizes, and the Savera-Areal lower group sizes, as the following Table 7-1 reveals:

Table 7-1: Mean Group Size per Observation Season

	Wahlenpark 2005	**Wahlenpark 2006**	**Bäckeranlage 2007**	**Savera-Areal 2007**	**overall**
Mean Group Size	2.7	2.6	2.5	2	2.4

Source: the author

Then, I examined the distribution of activity types grouped for observations seasons, gender, and age, starting with park observation seasons (Table 7-2). Note that there was no water in the basins in the Wahlenpark 2006 and the Bäckeranlage 2007, and the Savera-Areal has no playgrounds, which results in no activities of that type:

Table 7-2: Activity Type per Observation Season

Activity Type	Season				
	Bäckeranlage 2007	Savera-Areal 2007	Wahlenpark 2005	Wahlenpark 2006	All Seasons
Static Solitary	16.50%	22.51%	1.39%	4.86%	8.83%
Static Interactive	45.14%	49.82%	38.53%	48.84%	44.67%
Eating	23.17%	13.65%	3.95%	4.86%	10.82%
Dynamic Irregular	2.62%	5.54%	9.82%	16.60%	9.38%
Dynamic Regular	4.37%	5.54%	6.19%	11.10%	7.10%
Playgrounds	8.20%	0.00%	22.84%	13.42%	13.55%
Water	0.00%	2.95%	17.29%	0.32%	5.64%
Season Total	100.00%	100.00%	100.00%	100.00%	100.00%

Source: the author

On average, the majority of activities are Static Interactive (approx. 45 %): Visitors in the observed parks meet to chat and talk most of the time. Solitary activities account for only 9% of all activities, indicating that only few people visit the parks alone. This corresponds well with the observation of the overall average group size of 2.4 visitors. Consumption of food or beverages makes up for about 11%, although this represents only BBQ and picnic, not quick snacks. Strictly dynamic activities make up for only 16% of all activities, while the rest are playgrounds and water. This frequency distribution is modified by the park: Static solitary activities are much less common in the Wahlenpark and seem replaced by dynamic activities, playgrounds, and (in 2005) water.

The distribution of activity types according to gender is shown in Table 7-3. Interesting to note is the difference in activity type between male and female park visitors: The latter engage more in the static interactive type, while the former more often in the dynamic activity type, regular as well as irregular. At the playgrounds, however, gender is represented evenly everywhere.

Table 7-3: Activity Type per Gender and Observation Season

Activity Type	Gender	Season: Bäckeranlage 2007	Savera-Areal 2007	Wahlenpark 2005	Wahlenpark 2006	All Seasons
Static Solitary	Male	8.20%	12.26%	0.71%	2.15%	4.42%
	Female	7.61%	11.11%	0.82%	2.80%	4.39%
	Both	15.81%	23.37%	1.53%	4.95%	8.81%
Static Interactive	Male	20.73%	27.97%	15.39%	20.99%	19.90%
	Female	25.64%	21.07%	23.62%	27.45%	25.22%
	Both	46.37%	49.04%	39.01%	48.44%	45.11%
Eating	Male	12.30%	9.58%	1.65%	2.80%	5.87%
	Female	11.83%	4.60%	2.12%	2.15%	5.22%
	Both	24.12%	14.18%	3.76%	4.95%	11.09%
Dynamic Irregular	Male	1.17%	3.45%	4.70%	9.47%	5.08%
	Female	0.82%	1.15%	3.76%	7.10%	3.73%
	Both	1.99%	4.60%	8.46%	16.58%	8.81%
Dynamic Regular	Male	3.51%	4.60%	4.35%	10.23%	6.01%
	Female	1.17%	1.15%	2.12%	1.08%	1.42%
	Both	4.68%	5.75%	6.46%	11.30%	7.43%
Playgrounds	Male	3.75%	0.00%	10.81%	7.43%	6.67%
	Female	3.28%	0.00%	12.22%	6.03%	6.49%
	Both	7.03%	0.00%	23.03%	13.46%	13.16%
Water	Male	0.00%	0.77%	6.93%	0.00%	2.11%
	Female	0.00%	2.30%	10.81%	0.32%	3.49%
	Both	0.00%	3.07%	17.74%	0.32%	5.60%

Source: the author

A look at the distribution of activity type grouped for gender and age (Table 7-4) shows not surprisingly that senior visitors rarely engage in dynamic activity types at all, preferring static activities. There is a general shift towards more static activities with increasing age. While young boys and girls have similar activity patterns, with adulthood the activity patterns diverge, before becoming more alike later in life again. The larger number of regular dynamic activities observed can be attributed to male adults, as the following table reveals:

Table 7-4: Activity Type per Gender and Age Group

Activity Type	Gender	Age Groups				
		Children	Teenager	Adults	Seniors	All Age Groups
Static Solita-ry	Male	0.13%	0.50%	7.36%	6.67%	4.42%
	Female	0.25%	2.77%	6.82%	2.22%	4.39%
	Both	0.38%	3.27%	14.17%	8.89%	8.81%
Static Inter-active	Male	10.94%	18.14%	24.37%	28.89%	19.90%
	Female	11.32%	30.73%	29.92%	48.89%	25.22%
	Both	22.26%	48.87%	54.28%	77.78%	45.11%
Eating	Male	0.75%	7.05%	8.02%	6.67%	5.87%
	Female	1.26%	3.27%	7.66%	2.22%	5.22%
	Both	2.01%	10.33%	15.68%	8.89%	11.09%
Dynamic Irregular	Male	12.45%	8.06%	0.97%	0.00%	5.08%
	Female	9.69%	4.03%	0.90%	0.00%	3.73%
	Both	22.14%	12.09%	1.87%	0.00%	8.81%
Dynamic Regular	Male	4.78%	3.78%	7.18%	4.44%	6.01%
	Female	2.77%	0.76%	0.97%	0.00%	1.42%
	Both	7.55%	4.53%	8.14%	4.44%	7.43%
Playgrounds	Male	17.48%	7.81%	1.39%	0.00%	6.67%
	Female	17.36%	6.05%	1.57%	0.00%	6.49%
	Both	34.84%	13.85%	2.96%	0.00%	13.16%
Water	Male	3.90%	3.78%	0.90%	0.00%	2.11%
	Female	6.92%	3.27%	1.99%	0.00%	3.49%
	Both	10.82%	7.05%	2.90%	0.00%	5.60%

Source: the author

The aggregated data is less detailed but provides a larger sample, and therefore is especially suited for later comparison with the neighborhood population. First, however, I present the composition of gender and age groups per park season (Table 7-5 and Table 7-6). The difference between the male and female percentage and 100 are the "unknown" gender type.

Table 7-5: Gender per Observation Season

Gender	Season				
	Bäckeranlage 2007	Savera-Areal 2007	Wahlenpark 2005	Wahlenpark 2006	All Seasons
Male	47 %	50 %	41 %	58 %	47 %
Female	47 %	47 %	51 %	42 %	47 %
Total	13087	8944	2672	1231	25934

Source: the author

The genders are represented roughly evenly. Remarkable is the high fluctuation in the Wahlenpark: While there was a large male surplus in 2005, this frequency was practically reversed for 2006. These numbers are not absolute in the sense that, for example, 13087 visitors were observed. This is due to the snapshot technique, where one visitor could be counted several times. Nevertheless, the numbers are comparable. A statistical test showed no significant differences in staying duration for gender (see section 6.3.3). The following table shows the composition of age groups per observation season:

Table 7-6: Age Groups per Observation Season

	Season				
Age Group	Bäckeranlage 2007	Savera-Areal 2007	Wahlenpark 2005	Wahlenpark 2006	All Seasons
Children	15 %	17 %	47 %	40 %	20 %
Adults	75 %	73 %	44 %	56 %	70 %
Seniors	4 %	6 %	0 %	2 %	4 %
Total	13087	8944	2672	1231	25934

Source: the author

Adults make up the largest group of visitors, with very few seniors. However, the Wahlenpark clearly has a much younger visitor structure than the other parks. There are almost no seniors, but many children.

7.1.2 *Exploring the Spatial Distribution*

Cluster detection is a task/process of identifying one or more areas that are internally similar but different from their surroundings (Blok, Köbben et al. 1999). To explore spatial distributions visually, static maps are the simplest and most straightforward visualization technique and will be used first. The original data is in the form of points (vector data) that show the location of a specific event with several attributes. Each point represents one individual park visitor, thus I work with discrete, abrupt phenomena. From this, it follows that neither choropleth or proportional symbols, nor isarithmic maps are suitable, but only qualitative dot maps. Since a single dot represents exactly one individual event, the usual concerns of dot maps (dot size, unit value, and placement) are not relevant here. The Figures 7-1 to 7-4 show the corresponding visualizations grouped for park observation seasons.

Age: There are four age groups (children, teenager, adult, and senior). Since age is scaled ordinally and unipolar in nature, hue, and lightness in a sequential scheme seem the most sensible choice for visually encoding the age groups. Nevertheless, the large number of points suggests using hue for a higher contrast and clearer distinction for points that are close. The spatial distribution of the age categories seems largely as expected. The elderly visitors depend on the park infrastructure and use benches and tables, so they gather at these respective places. Interestingly, those are usually located at the periphery. Children also cluster around park infrastructure that provides opportunities for playing games, such as playgrounds and water basins or pools. Visitors in the middle age category make the most use of open spaces, almost exclusively occupying these for diverse activities.

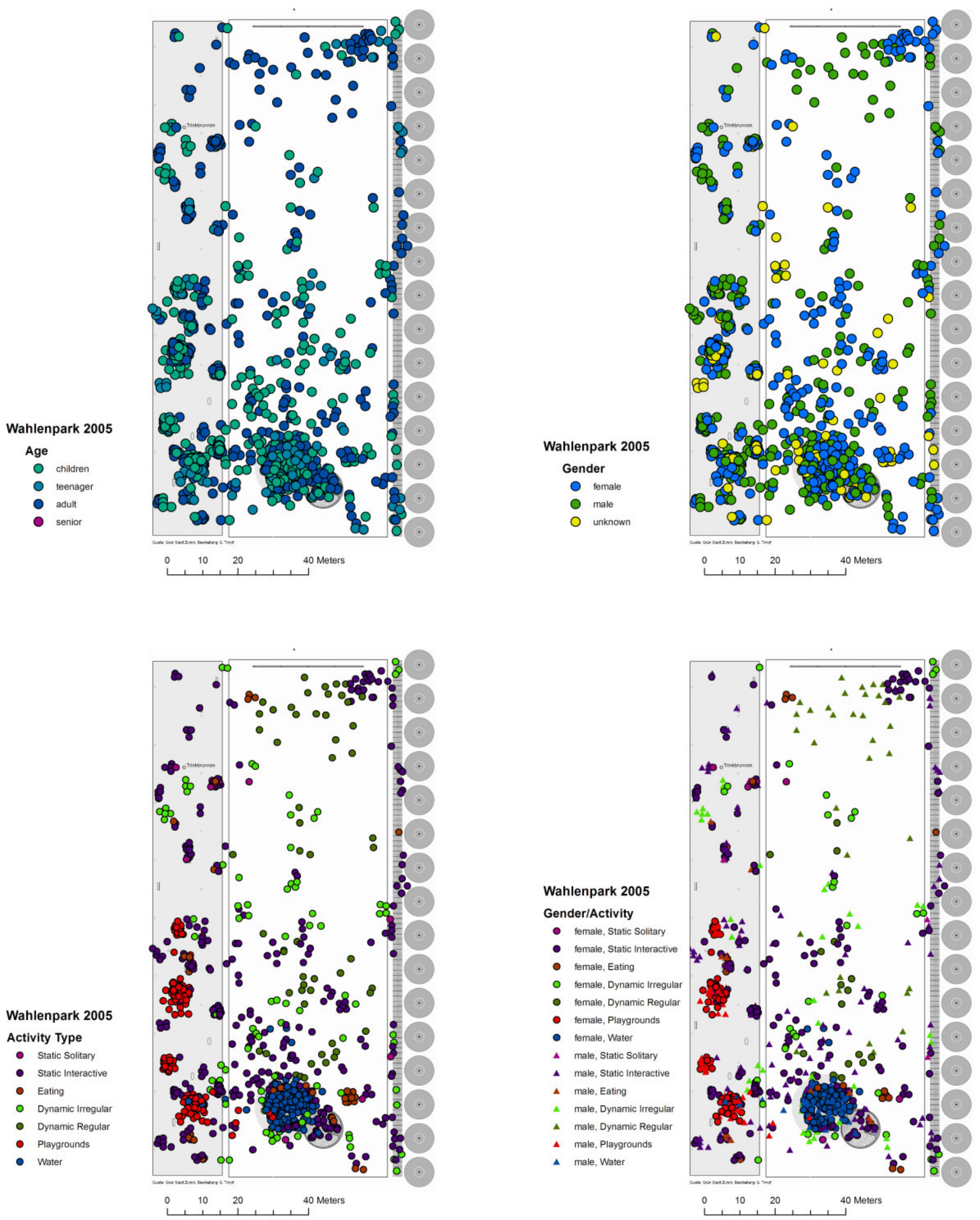
Gender: Having only three gender groups (male, female, and unknown), this nominal data can be symbolized using orientation and shape of symbols, or hue. I decided to use hue with an univariate visualization. Generally, the distribution according to gender seems randomly dispersed. However, there might be slight tendency of male park visitors to use the open spaces more than female visitors do, especially in the Wahlenpark. There, the clear separation of park areas exaggerates such trends.

Activity: The seven activity groups (Static Solitary, Static Interactive, Eating, Dynamic Regular, Dynamic Irregular, Playgrounds, and Water) are nominal in scale, so different hues or orientation and shape are feasible. The problems of choosing seven clearly separable different shapes or hues suggests using a combination, i.e. grouping static and dynamic activities respectively and using the second variable (shape or hue) for finer discrimination. Most of the activities take place where expected, i.e. as offered by the park infrastructure. In this respect, the large open spaces are the most interesting features for analysis, since one can expect the greatest diversity of activities competing for the same space. It seems that activities involving more movement (e.g. football) are located at the periphery and clustered.

It is also preferable to show multivariate visualizations to examine relations between the variables. The large number of observed visitors and events makes a comparison between multiple maps difficult. For that reason, I combined several attributes in the maps:

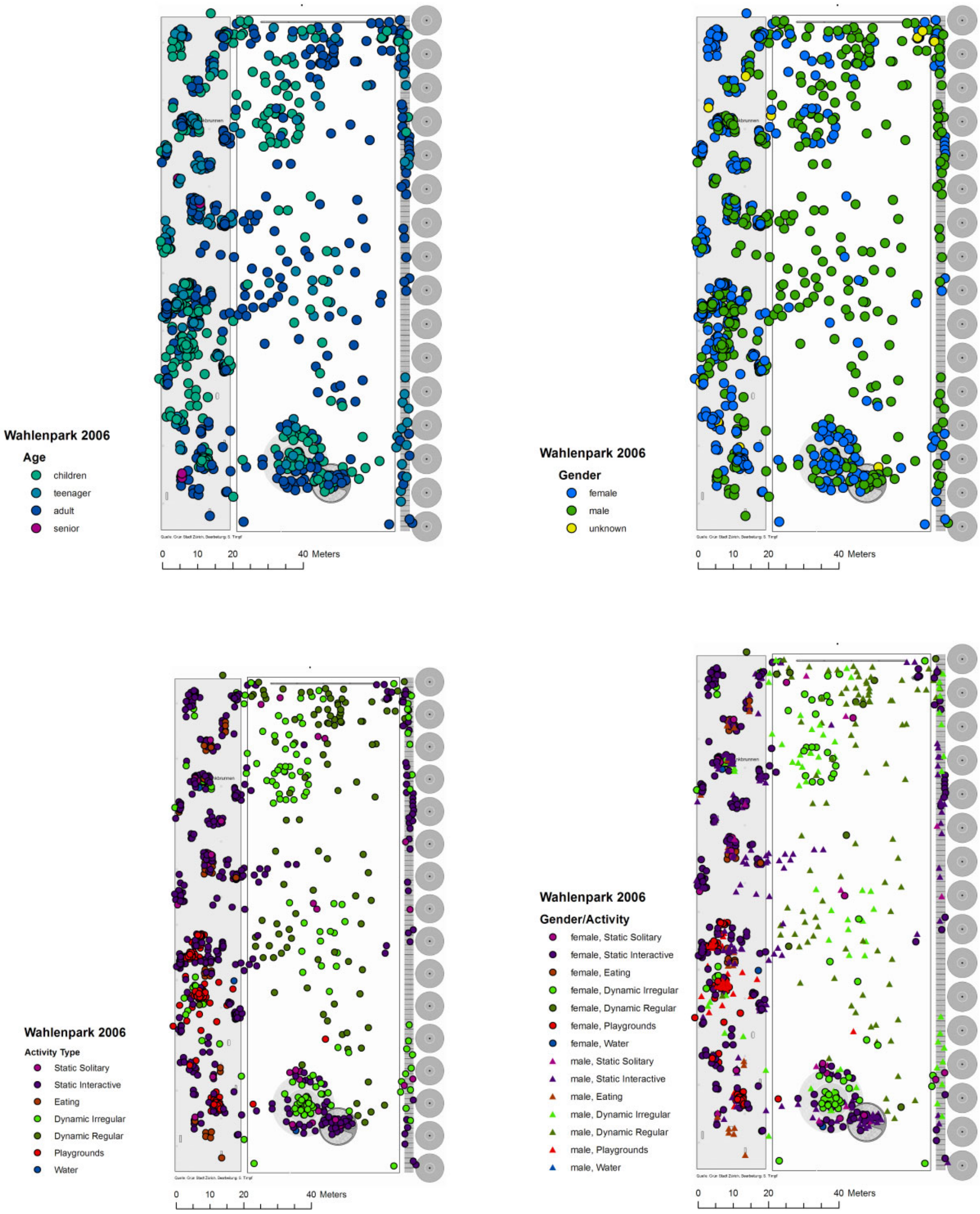
Gender and Activity: The large number of categories for a combined display of gender and activity complicate the choice for adequate symbolizations, although the dual nature of gender makes it easier to read and interpret these visualizations. Shape is used for gender and different hues for activity types. There are trends that contradict perceived or expected distributions. While a common assumption is that male visitors have a larger share of the activities involving lots of movement and occupy central spaces with it (Paravicini 2002), the distributions observed do not seem to exhibit such a pattern. While there seem to be indeed more males carrying out such activities, in the Savera-Areal and the Bäckeranlage these activities are located at the periphery. Only in the Wahlenpark seem such expected patterns likely, albeit in a weak form.

Figure 7-1: Dot Maps Wahlenpark 2005



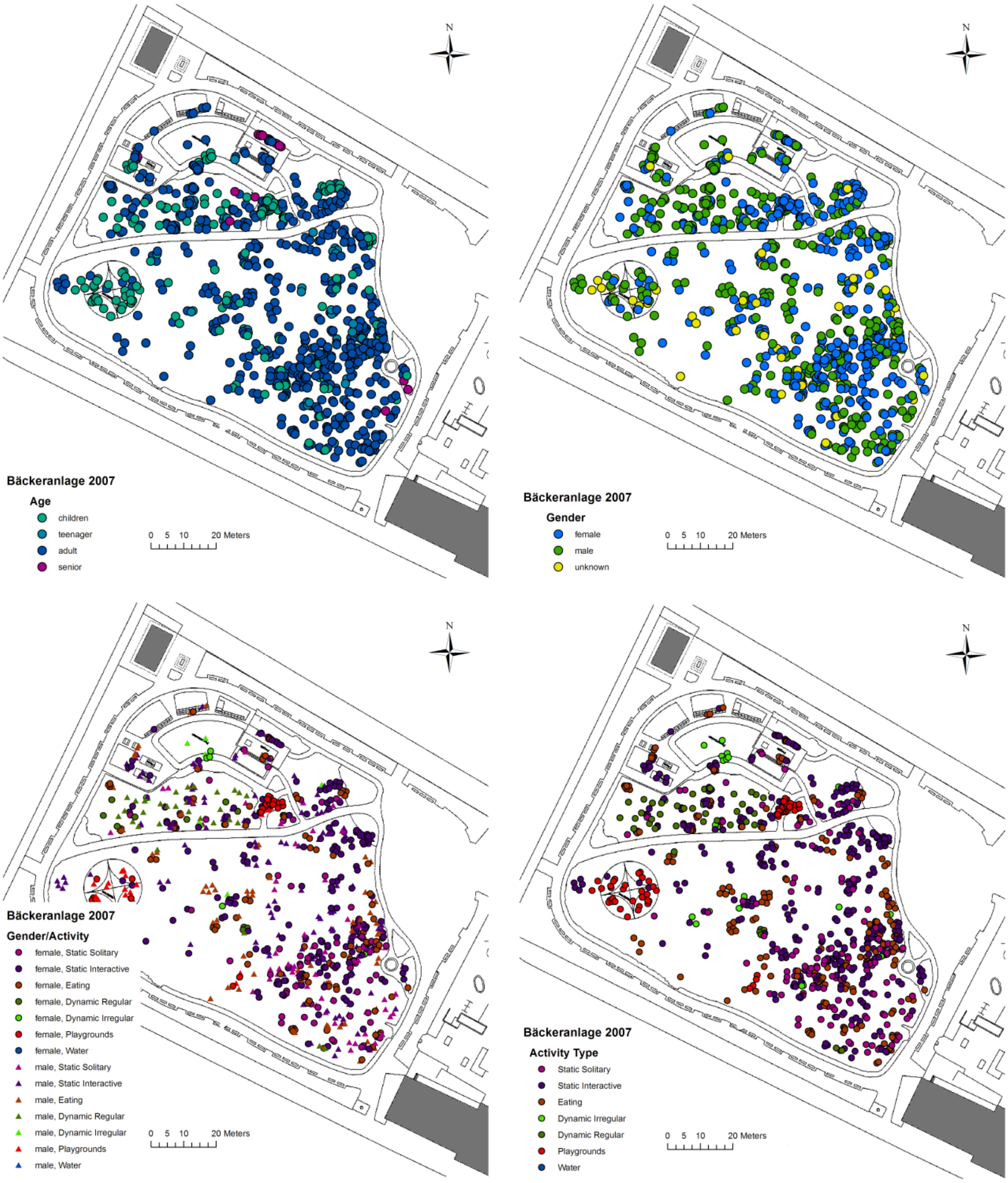
Source: own design

Figure 7-2: Dot Maps Wahlenpark 2006



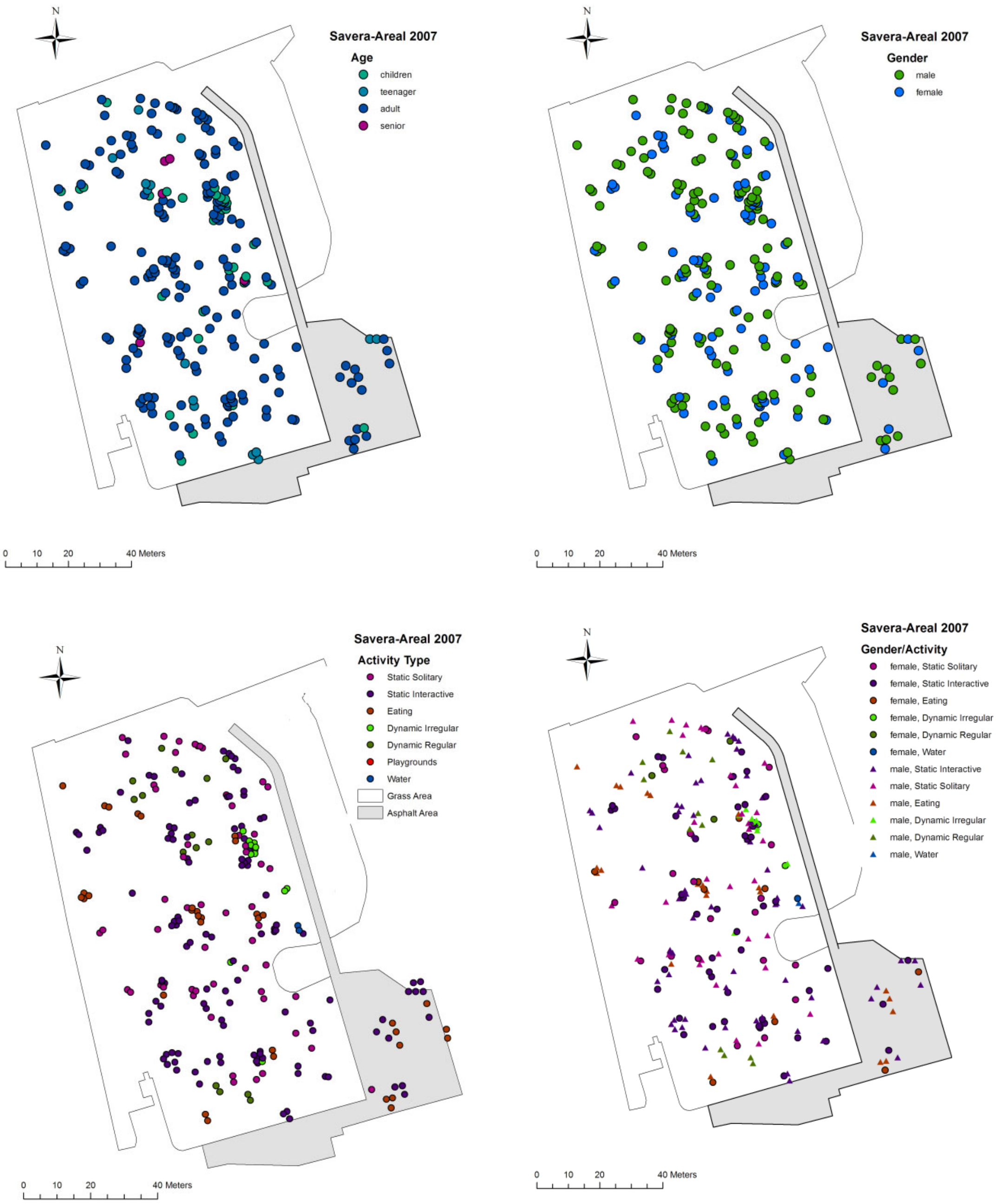
Source: own design

Figure 7-3: Dot Maps Bäckeranlage 2007



Source: own design

Figure 7-4: Dot Maps Savera-Areal 2007



Source: own design

Age and Gender: A promising approach is the use of shape for gender and hue or lightness for age (see description of univariate visualizations). However, an altogether differently approach was chosen for this attribute combination (see section on field-based data visualizations below).

Age and Activity: The number of combinations makes this visualization very difficult to read and interpret. A reduction of age categories and activity types is necessary. Because only trivial information was expected to be extractable, this visualization was not implemented.

Activity, Age, and Gender: Even with a reduced number of classes for age and activity, too many classes remain to represent them adequately in a dot map.

Judging from a qualitative visual examination, there seem to be specific distributions of visitors. After having identified possible clusters and hot spots of space use (pattern recognition), the next step would be to compare them spatially among parks, temporally between time windows, and according to their attributes (pattern comparison). For this, small multiples are a promising technique. However, too much detail is lost with small multiples of the dot maps, because of the large number of features to be mapped and their corresponding small size. The technique of small multiples was later employed for the visualization of the kernel density estimates.

The interactivity required for this type of exploratory knowledge production is high. However, an adequate interactivity is possible, since no computations are necessary and the changes in the display can be acquired with the simple tasks of a definition query for selecting specific events and manipulation of symbology. The level of abstraction of the dot maps is very low. The concept of “one point = one park visitor” is easy enough to grasp for lay users.

A common problem occurring in the static dot maps is the occlusion at hot spots of activities, where multiple points (i.e. events) overlap. This problem becomes more severe the more attributes are mapped, i.e. when shape has to be used as visual variable. It also renders orientation as visual variable practically useless. A possible solution is the disaggregation of the temporal dimension by using the third dimension for display (i.e. symbology as sign-vehicle), which is discussed in the following section.

7.1.3 *Exploring the Temporal Distribution*

Before analyzing the spatio-temporal distribution, I examined first the exclusively temporal distribution of activity, gender, and age. The temporal distribution of activity types along the observation periods between 12 pm and 8 pm is shown in the following Table 7-7:

Table 7-7: Activity Type per Observation Period

Activity Type	Observation Period (hours)					
	12-14	14-16	16-18	18-20	17-20	All Observa-tion Periods
Static Solitary	13.65%	13.22%	10.47%	3.88%	1.39%	8.54%
Static Interactive	47.95%	53.73%	52.66%	51.75%	38.53%	48.37%
Eating	24.37%	6.25%	6.48%	6.47%	3.95%	10.26%
Dynamic Irregular	7.21%	13.70%	14.78%	11.13%	9.82%	10.91%
Dynamic Regular	1.36%	5.77%	8.31%	18.37%	6.19%	7.48%
Playgrounds	4.78%	7.09%	5.48%	8.28%	22.84%	10.05%
Water	0.68%	0.24%	1.83%	0.13%	17.29%	4.39%
Observation Periods Total	100.00%	100.00%	100.00%	100.00%	100%	100.00%

Source: the author

Most remarkable is the decreased proportion of static solitary activities at the later hours. It is replaced by dynamic regular activities. Also reduced at the later hours are food-related activities, while static interactive activities stay at the same level all the time.

Next, the gender distribution is examined in Table 7-8:

Table 7-8: Gender per Observation Season and Observation Period

Season	Gender	Observation Periods (hours)				
		12-14	14-16	16-18	18-20	17-20	All Observation Periods
Bäckeranlage 2007	Female	46 %	50 %	48 %	43 %		47 %
	Male	45 %	44 %	45 %	54 %		47 %
Savera-Areal 2007	Female	49 %	47 %	43 %	49 %		47 %
	Male	47 %	48 %	54 %	49 %		50 %
Wahlenpark 2005	Female					51 %	51 %
	Male					41 %	41 %
Wahlenpark 2006	Female	44 %	49 %	48 %	36 %		42 %
	Male	56 %	51 %	49 %	63 %		57 %
All Seasons	Female	47 %	48 %	47 %	43 %	51 %	51 %
	Male	47 %	47 %	47 %	54 %	41 %	41 %

Source: the author

The gender structure in the Bäckeranlage shows a clear trend with later hours: Towards the evening, there is an increasing share of male visitors, while the amount of female visitors and visitors of unknown gender declines. Since the unknown group represents mostly infants, this could be interpreted that mothers and little children leave the park, and are replaced by male adults. A similar trend exists in the Wahlenpark in 2006. In the Savera-Areal, there are fluctuations, but not a clear trend.

This general trend in relation to the gender structure over time is also observable for age groups: The number of smaller children decreases later in the day, while the number of adults and seniors increases slightly. This trend is similar in all parks, as Table 7-9 below shows.

Table 7-9: Age Groups per Observation Season and Observation Period

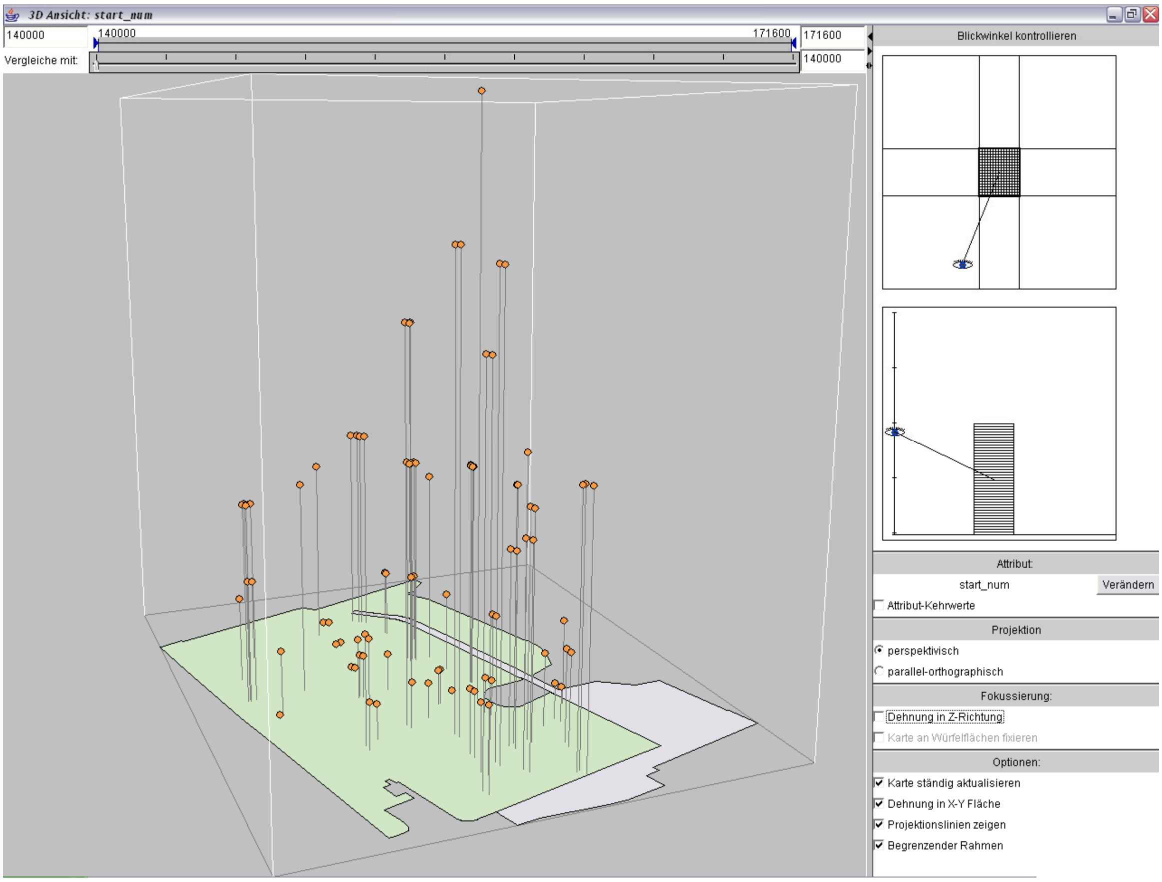
Season	Age Group	Observation Periods (Hours)					
		12-14	14-16	16-18	18-20	17-20	All Observation Periods
Bäckeranlage 2007	Children	16 %	14 %	15 %	16 %		15 %
	Adults	74 %	78 %	75 %	76 %		75 %
	Seniors	2 %	1 %	4 %	6 %		4 %
Savera-Areal 2007	Children	14 %	20 %	17 %	13 %		17 %
	Adults	76 %	71 %	74 %	79 %		73 %
	Seniors	6 %	5 %	6 %	5 %		6 %
Wahlenpark 2005	Children					47 %	47 %
	Adults					44 %	44 %
	Seniors					0 %	0 %
Wahlenpark 2006	Children	41 %	61 %	46 %	31 %		40 %
	Adults	59 %	29 %	51 %	67 %		57 %
	Seniors	0 %	9 %	0 %	0 %		2 %
All Seasons	Children	18 %	20 %	16 %	19 %	47 %	20 %
	Adults	73 %	71 %	74 %	75 %	44 %	70 %
	Seniors	4 %	4 %	4 %	5 %	0 %	4 %

Source: the author

In order to represent the detailed data with both spatial and temporal dimensions, I used display time (animations) and symbology (space-time cubes) as sign-vehicles for the temporal data dimension. It is not sensible to use the data aggregated into observation seasons here, since the observations took place over a considerable span of real time (several weeks). Instead, I had to look at each observation session separately. Conceptualizing time in a cyclical manner and aggregating all observations in one park according to the observation periods would have required too much processing for an exploratory analysis.

Space-time-cubes display individual events display with the z-axis for the temporal dimension. Two examples are given in the following Figures 7-5 and 7-6. They use the respective start time as base height (14:00 for the Savera-Areal, and 12:00 for the Wahlenpark):

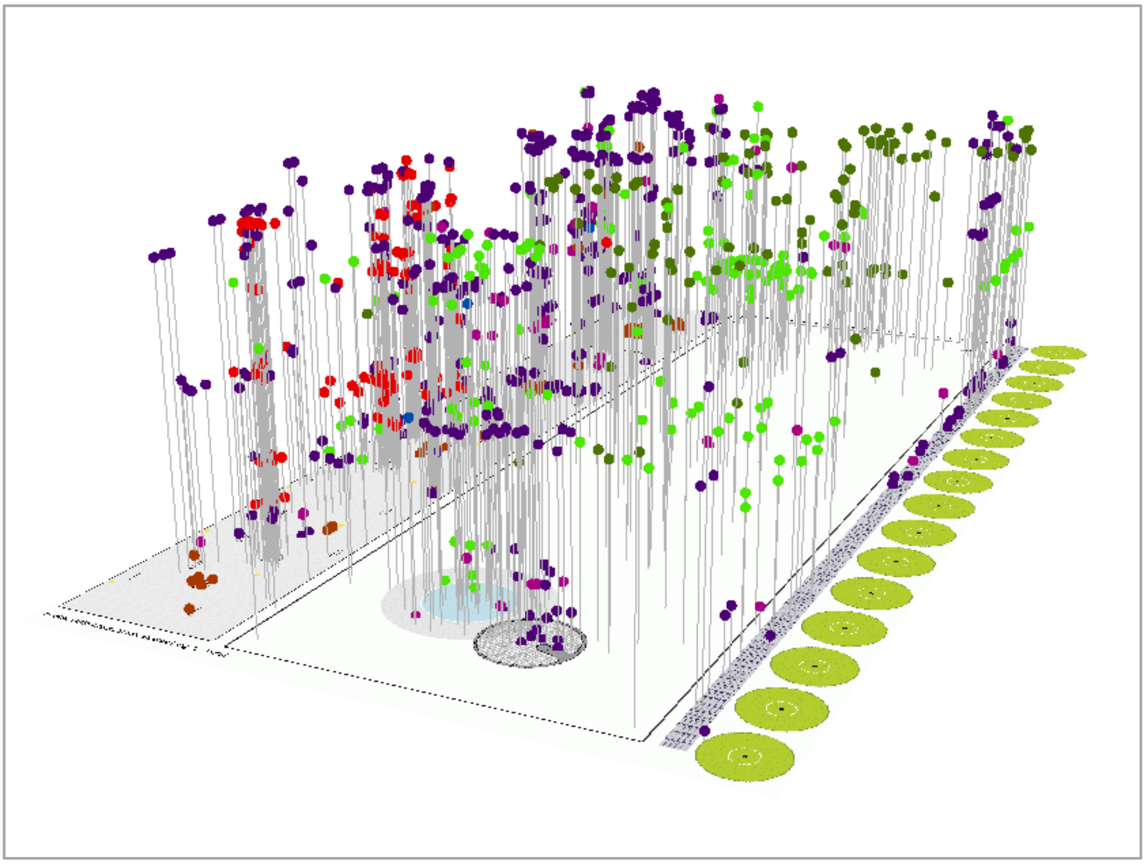
Figure 7-5: Example Space Time Cube Savera-Areal 2007



Source: own design; data used: 16.06.2007, created with CommonGIS

The problem here is that a very large number of visualizations would result if each observation session is explored separately. However, an aggregation on the level of observation seasons introduces the problem of cluttering (the same color scheme for activities was used as for the 2D static maps):

Figure 7-6: Example Space Time Cube Wahlenpark 2006



Source: own desig, created with ArcScene

While the creation of space-time cubes is quickly accomplished and the display interactively manipulated, the visualizations are very complex and become perceptually and cognitively overwhelming. The cluttering introduced by the large number of points made the reasoning or deductions of spatio-temporal distributions very difficult. This is a common problem with this visualization technique and has not been solved adequately yet. A workaround would be to reduce the number of dots represented by selecting only those that fall within a specified time window. However, in this case the end time or the duration (by extruding the points) would have to be depicted. Otherwise, one would miss the events which start time lies outside the time window, but which are still active in the park.

For these reasons, I decided to employ this method only if interesting patterns during specific observations sessions were discovered with the other analysis and visualization methods.

Another approach is to use time itself as sign-vehicle for the temporal data dimension, creating animations. An important requirement for the animation is that a dot is displayed until another dot with the same ID appears (i.e. only the current event of one visitor is displayed, but as long as it lasts).

Simple animations were generated with the ArcGIS Tracking Analyst and Create Time Layer / Animation toolset. Unfortunately, the creation of animations with the available software proved to be very time-consuming. Additionally, the interactivity is low, because usually an Animation Tool such as the one included in ArcGIS computes the animation in advance and later allows only simple VCR-type interaction (i.e. stop, play, and pause). The symbology needs to be manipulated before the animation is created.

The level of abstraction is very low. The analogy of “one dot = one activity” is intuitive, as is the use of time as sign-vehicle for temporal data. However, again the visualization is overwhelming, straining both perception and cognitive limits of an analyst. The larger number of features probably leads to many events being missed during playback of the animation.

Since one animation per observation session would be needed, the large number of animations to be interpreted led to the conclusion that a temporal analysis would have to wait until suited methods for mining the data are developed, or until interesting patterns for specific observations were found that made this type of visual analysis promising.

7.1.4 *Additional Hypotheses on Space Appropriation*

In addition to the research questions that form the basis of this work and were described in Chapter 1, the exploratory visual analysis allows the formulation of hypotheses of the space use and appropriation in the observed parks. It is imperative to be careful at this point not to formulate hypotheses that will be affected by the pattern of samples taken (i.e. the observation schedule). I will statistically test the distribution of gender and age groups between a park and its surrounding neighborhood. If there are significant differences, one might suspect that the underrepresentation of an age or gender group is a sign of exclusion, and by that of a lack of social sustainability.

The null-hypotheses to be tested are:

1. There is no significant difference in the gender structure between the observed sample of park visitors and the neighborhood population.
2. There is no significant difference in the age structure between the observed sample of park visitors and the neighborhood population.

The definition of surrounding neighborhood is given in the following section and builds on the theoretical background developed in Chapter 2.

The event data is spatial in nature and should enable the analysis of the spatial distribution of the park visitors. From that distribution, one can argue whether there might be any intra-site displacement processes. The hypotheses to be tested are:

3. There is no significant spatio-temporal clustering of males or females in the parks.
4. There is no significant spatio-temporal clustering of age groups in the parks.
5. There is no significant spatio-temporal clustering of activities in the parks.

It is necessary to check where these clusters are located in order to say more about exclusion or domination occurring. If a large number of small clusters are dispersed equally over the whole study area, one can assume a “natural” clustering of visitors.

7.2 Object-Based Computation of Space Appropriation

In this Chapter, the model described in Chapter 2 is implemented. Space appropriation and potential crowding are computed using active and passive spaces, i.e. activity footprints and personal spaces.

Chapter 5 introduced three methods for an object-oriented approach: Minimum convex polygons, Voronoi tessellation, and simple buffers. After having examined the observed data, minimum convex polygons and Voronoi tessellation do not seem feasible:

Minimum convex polygons require a large number of events per entity, i.e. locations per park visitor. Most of the visitors have only a single or very few spatial locations during a single park visit. Therefore, the data simply is not suitable to create minimum convex polygons. Voronoi tessellation is not suitable because it would lead to very small cells of appropriated space in hot spots, and the method of partitioning space is not compatible with the model.

7.2.1 *Buffers as Approximation of Space Appropriation*

Discrete buffers around objects are one of the most established and straightforward methods of spatial analysis and seem feasible for the observed data. In this case, the buffers are used to represent personal spaces and activity footprints. This approach was realized using a loose coupling of GIS software with external Java code.

A first implementation of programmatically computing the model was done in the form of a master thesis supervised by the author of this thesis. The following description refers to the workflow as developed in the master thesis.

At first, the activity footprints and personal spaces for each park user are created by buffering single events. An intersection module then creates the overlapping shapes by performing Boolean operations between each of the original shapes, allowing for the fact that members of the same groups do not create conflict between each other. This step is repeated, until all the geometry is correctly fragmented. Since this process generates multiple duplicates of shapes, the obsolete ones are removed, leaving only the significant zones. Their original attributes are stored in a separate array to determine their conflict potential in the next step.

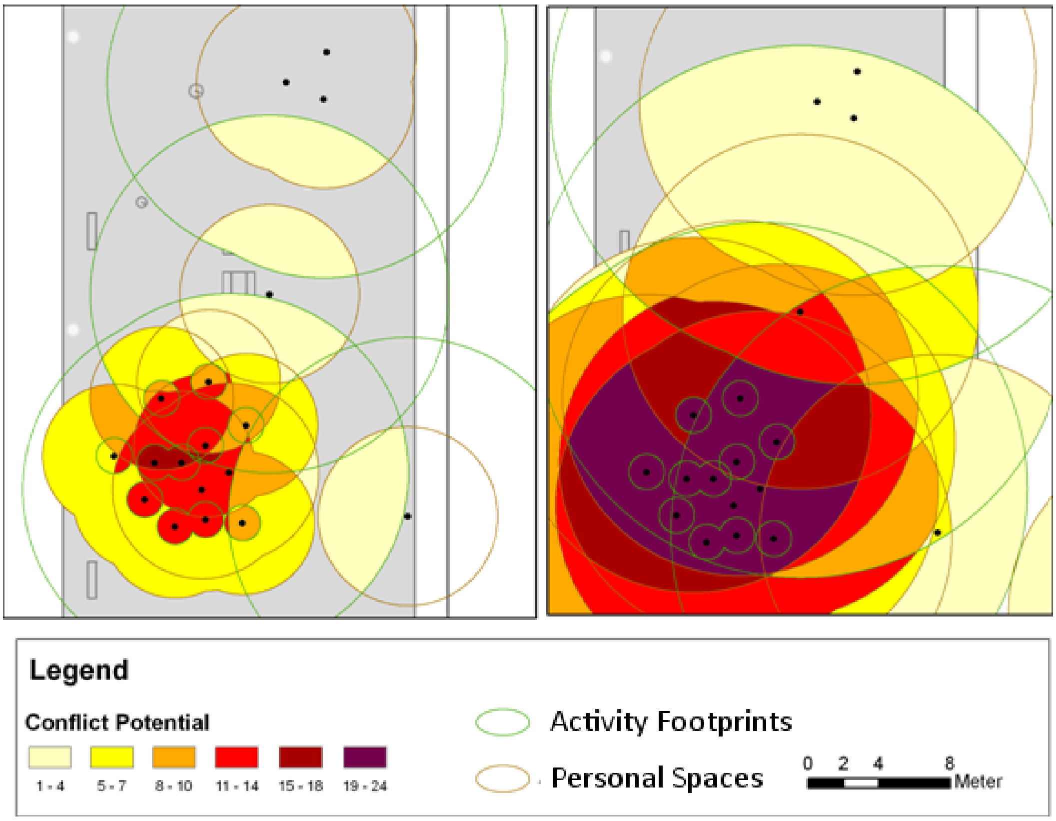
Each of the remaining shapes still possesses information on the original contributors. In densely populated areas, multiple park users contribute to the crowding potential of a shape. The actual crowding values are calculated according to weights set in configuring step (compare section 4.3) and stored in a separate array.

The user can monitor the automated processes step-by-step and is able to supervise visually the intermediate results, and to decide either to continue processing or to rerun the code with different settings altogether before initiating the next step. Nevertheless, the Java program also allows full automation of the processing, to swiftly produce results with different presets (shape, weights) or different points in time (for animations). The process can be started by initializing the program with a series of raw data and/or presets for shapes and weighting. The results can then be compared, which may help to determine sensible presets for shape and weights or to produce animations as well. However, at this time the interval of the raw data is too big to produce sensible animations, but it might be reduced by tracking data in the future.

7.2.2 *Object-based Representations of Space Appropriation*

The object-based computations produce two-dimensional representations of space appropriations with values at an interval scale, with the data being abrupt but continuous in nature (MacEachren 1995). The traditional choropleth map is therefore a valid choice for visualization. Because there are many irregular shapes nested within each other, the visual variables of spacing, size, perspective height, orientation, shape, and arrangement would produce very complex patterns that might distract from the actual spatial pattern of space appropriation one is hoping to detect. Therefore, mainly hue and lightness seem appropriate. The following Figure 7-7 shows two realizations of the algorithm for the Wahlenpark with different radii for activity footprints and personal spaces: On the left hand side, the radii are smaller than on the right hand side, resulting in more overlap (here termed "conflict potential") of activity footprints and personal spaces.

Figure 7-7: Example for Object-based Representation of Space Appropriation



Source: Lusti (2008), editing Ostermann, Frank

Since the space appropriation is only valid for a specific point in time, a static visualization is only useful with small multiples representing the recorded snapshots in time. Otherwise, information is either lost through aggregation during analysis or occlusion during visualization. Every time a change occurs, the buffers are recalculated and a new snapshot is produced. These snapshots can be animated, producing thematic animations (Lobben 2003). The same problem that was mentioned in the section on exploratory analysis remains here: Too many animations that need to be compared visually by the user.

The interactivity is very low, because the computations have to be carried out in advance and are not possible on the fly. Therefore, the effects of different parameter values can only be observed by running the calculation multiple times with the desired values and then compare the results.

The complexity of the map is high, because there are many different shapes having sometimes drastically different values. This makes an interpretation by the user very challenging. On the other hand, the information about participating park visitors is still available and can be accessed through simple spatial queries.

An immediately apparent problem is the sharp jumps in potentially conflicting uses of space with in very small areas. It shows clearly the shortcomings of an object-based representation of human space use and appropriation, because the sharp boundaries and large differences in values between adjacent shapes indicate that the main characteristics of human space appropriation are not adequately represented.

7.2.3 *Applying Concepts from Time Geography*

As described in the Chapter 5, the exact spatial-temporal location of the park visitors is not known at all times for dynamic activities. This renders the generation of space-time-paths for dynamic activities difficult. For static activities, the exact spatio-temporal location is known, but the observations show that park visitors rarely change their location, which would result in almost vertical space-time paths

A space-time prism shows the locations in space and time that are accessible within given constraints. However, the potential path areas derived by plotting the prisms to a planar surface would regularly exceed the boundaries of park, because the parks are rather small. The time geographic framework does not work at the micro scale: Once the park visitors have chosen their location, they do not move much, or their movement is not subject to the constraints of time geography (except to a certain extent subject to coupling constraints).

7.3 Field-Based Computation of Space Appropriation

It is obvious that the discrete representation does not capture the important aspect of the vague boundaries of human space appropriation, instead suggesting crisp changes in space appropriation and drastic, spatially not correlated differences in potential crowding and conflict.

An alternative approach to modeling space appropriation is a continuous, field-based one. This means that every park user's influence on space use and appropriation is computed for a grid that represents the whole park area under analysis. Space use, space appropriation, and potential crowding become a function of location. The advantage for the analysis is the possibility to represent the space appropriation in a way that reflects its characteristics – it is continuous and field-based in nature and has vague boundaries.

The short overview of methods in Chapter 5 showed that only kernel density estimates suitably represent the model in a quantitative way. For this reason, the field-based continuous implementation presented is based on that method.

7.3.1 *Kernel Density Estimates as Approximation of Space Appropriation*

In detail, the activity footprints and personal spaces are generated by calculating a density surface for each single visitor or group of visitors carrying out an activity together. Using different parameters for the calculations according to activity type, multiple density layers are generated that can be checked for overlaps, i.e. potentially crowding situations. At the same time, they can give an estimation of the relative intensity of the potential crowding and hint at the probability of actual confrontation or conflict.

For each group of visitors, two kernel densities were calculated: One for the activity footprint, and one for the personal space, similarly to the discrete buffer approach. As already mentioned in Chapter 4, the different types of activities have specific activity footprints and personal spaces. The following parameters influence the shape of a kernel density estimate:

- Function: The type of function used, e.g. quartic Gaussian.
- Symmetry: Whether the same function is used for x- and y- values.
- Search Radius or Bandwidth: Controls the spread of the kernel.
- Population: Represents the volume underneath the generated surface.

For reasons of efficiency and constraints on the timeframe of the project, the kernel density estimation function of ArcGIS was used. It employs a symmetric quartic Gaussian function, which is normalized to a volume of one, reaching a value of zero at a specified search radius distance from the input data point. The volume under the surface can be modified by a population field value for the input data point. Although other functions and asymmetric shapes are possible through extensions, their programming interfaces are not accessible for automation. This leaves bandwidth and population as easily adjustable parameters.

Generally, a larger bandwidth was chosen for activities involving much movement in space, thereby simultaneously representing two aspects: One, the greater uncertainty of location, because the probability of being at a specific location is less with dynamic activities. Second, at the same time an increasing amount of space is used. It is important to keep in mind that the values at the current stage of research are assumptions derived from own experience and observations, and have to be verified in an evaluation process and refined accordingly. The parameter values were changed for several runs. The following Table 7-10 provides a list of the values used for the examples in this section:

Table 7-10: Search Radii per Activity Type

Activity Type	Search Radius (in Meters) of Activity Footprint	Search Radius (in Meters) of Personal Space
Static Solitary	5	15
Static Interactive	10	10
Eating	15	15
Dynamic Irregular	15	5
Dynamic Regular	15	5
Playgrounds	10	5
Water	15	5

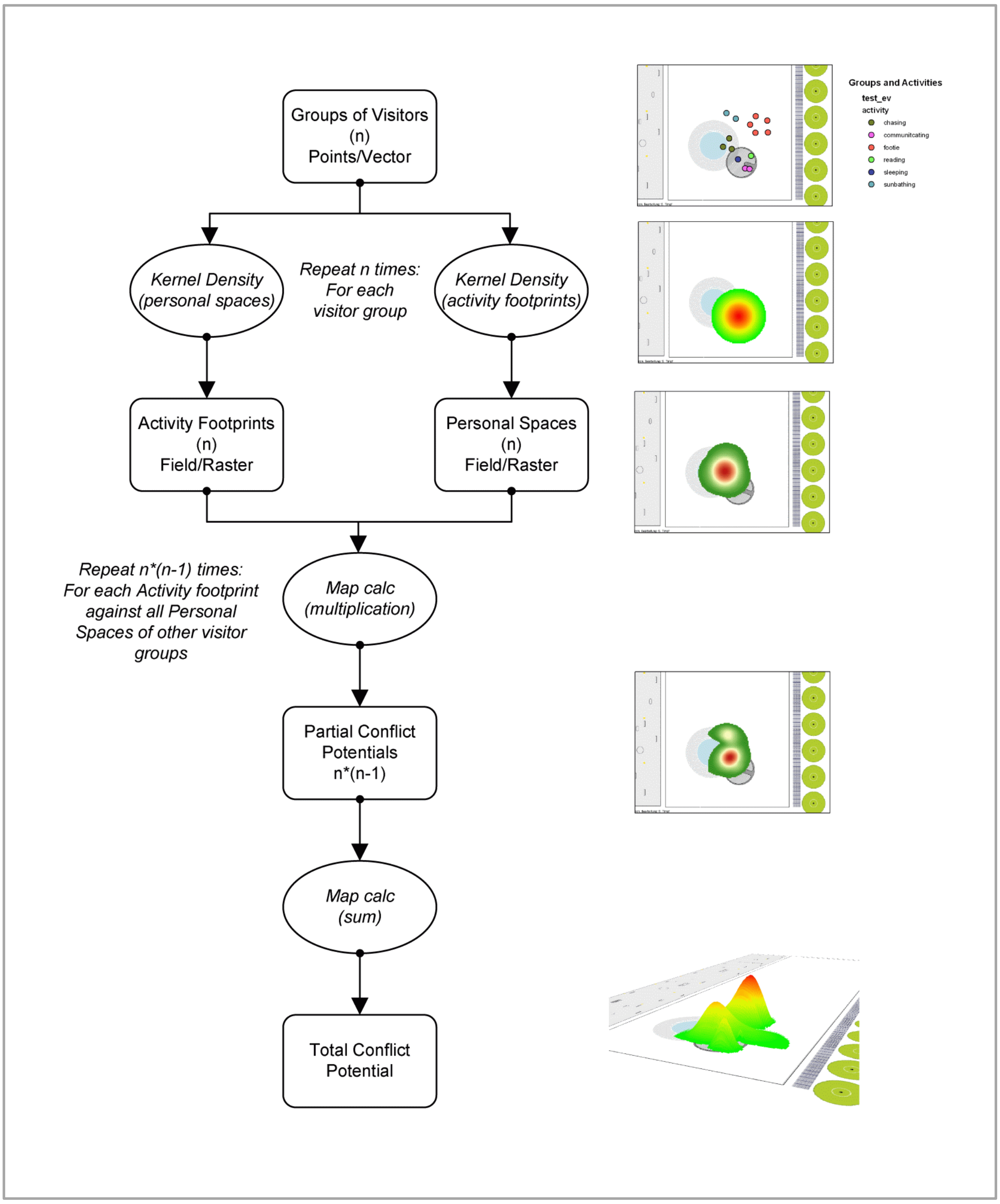
Source: the author

The search radius for activity footprints is an arbitrary choice, based on empirically supported assumptions. The search radius for personal spaces is a multiple of the values shown in Table 4-2.

Population was not used as parameter. It is not necessary to give the individual groups an additional weighting, because for each event, the whole scene is calculated.

Each group’s activity footprint raster layer was then checked against the personal spaces of all other groups via map multiplications, so that only overlapping spaces would retain any value at all (a multiplication by zero returns zero). The resulting fields of potential crowding and space appropriation were then summed. The following illustrated Figure 7-8 shows the workflow of the computation schematically.

Figure 7-8: Analysis Workflow of Field-based Computation



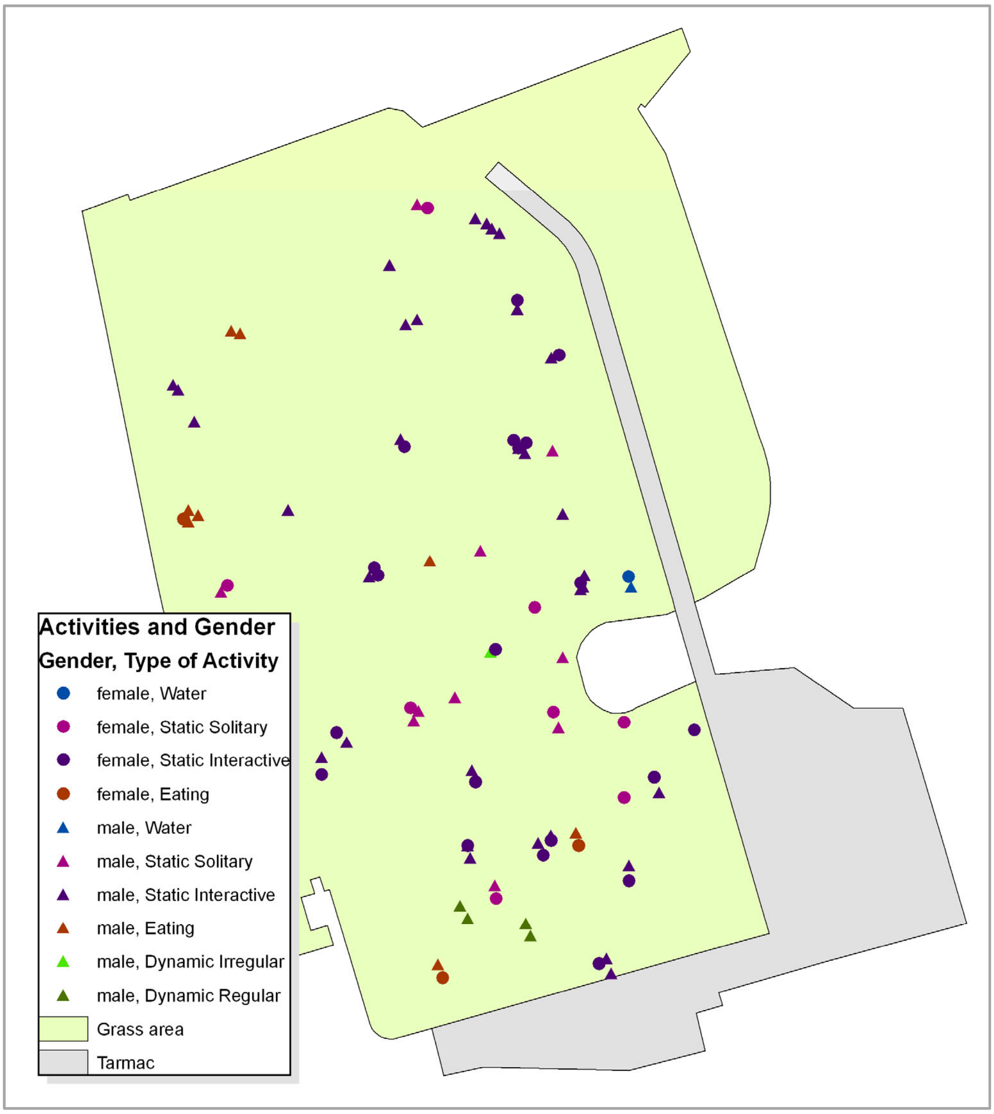
Source: the author

In a next step, the temporal dimension was included by repeating this process for every moment in time when one or more events happened. In detail, a list of all unique event times was assembled (i.e. all unique start times). Then, for each item in the event times list, all the points/events were selected where a) the start time is equal to or less than the current event time value, and b) the end time is greater than the current event time value. For this selection, the described calculation was performed, resulting in a set of snapshots of potential crowding situations. The programming was implemented using VBA scripting in conjunction with the ArcGIS Geoprocessor (for the scripting code, see Appendix).

7.3.2 *Field-based Representations of Space Appropriation*

The workflow described in the previous section has been applied to several datasets, of which one serves as an example here. I have chosen the same dataset that was used for one example of a space-time cube (see Figure 7-5), i.e. the observations session of June 16, 2007 in the Savera-Areal. The following Figure 7-9 shows again the temporally aggregated distribution of activities.

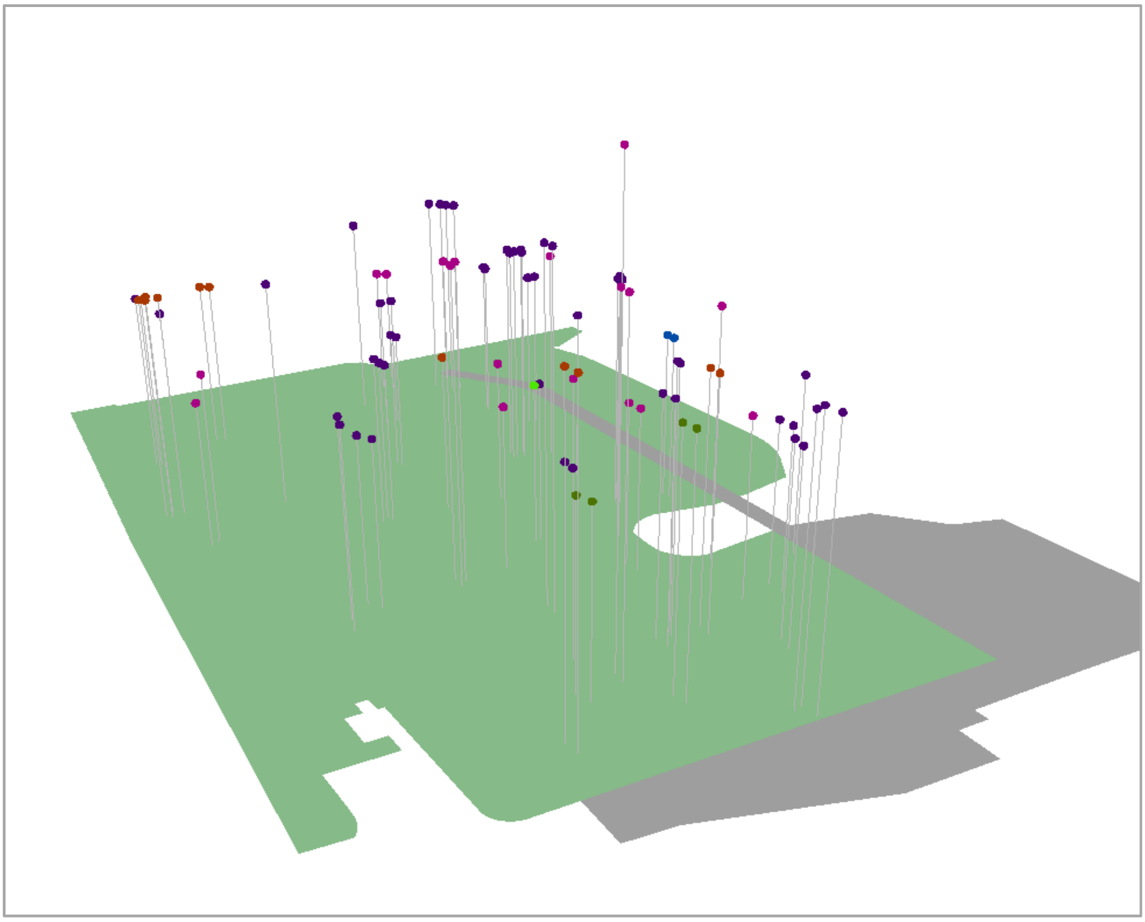
Figure 7-9: Dot Map Activities and Gender Savera-Areal 16/06/2007



Source: own design

The next Figure 7-10 is the same dataset with the same symbolization as a space-time cube (the legend could not be included in the output due program constraints):

Figure 7-10: Space-Time Cube Activities and Gender Savera-Areal 16/06/2007



Source: the author

The output of snapshots can be animated or compared as small multiples. The absolute values of the results are dimensionless, but at an interval scale. That means that computations for different observation sessions are comparable. The originally discrete data has been transformed into continuous and smooth data. The appropriate visualization technique is therefore an isarithmic depiction. The most promising symbolization is continuous tones, analogous to unclassified choropleth mapping. This symbology represents well the continuous nature of space appropriation, without introducing arbitrary class limits. The lightness value is proportional to the value of the surface, employing a sequential scheme. Contour lines could be used to distinguish values from one another. The resulting snapshot maps can be viewed in a static 2D visualization as small multiples, with a time stamp added for ease of reference. Figure 7-11 shows such a sample of small multiples with a time stamp added:

Figure 7-11: Example for Field-based Space Appropriation Savera-Areal

Source: the author

Again, these snapshots can be used for a thematic animation. A problem is the temporal discontinuity of the data. The disappearance of a few park visitors and the resulting drastic changes in space appropriation occur seemingly instantaneous and unexpectedly, not allowing the observer to adjust and compare different states. Some kind of temporal smoothing seems required. The third dimension as an additional visual variable does not offer more information carrying capacity in this context. It can be used to make the concept of densities more readily graspable by lay users by showing 2,5 D surfaces of density. In a static true 3D visualization, the third dimension could be used to represent the temporal dimension. In that case, volumes using voxels would represent the space appropriation (compare taxels in section 3.3.2). Unfortunately, there is no way to show adequately these volumes because of occlusion. Several slices would have to be used. Currently, the author has not been able to implement a computation of space appropriation that uses voxels instead of snapshot grid cells. This type of visualization would be aimed at the professional researcher, since a great deal of abstracting and prior knowledge is needed for the interpretation.

The interactivity for the depicted visualizations is low, although the symbology of the density surface can be manipulated easily to suit the user’s needs. The low interactivity is due to the same problem the discrete buffer representation encountered, i.e. the time the computations take and the fact that they cannot be performed on the fly. Once created, the parameter values cannot be adjusted without rerunning the entire computation. The interactivity is even lower for animations because of the additional steps necessary to create an animation out of the snapshots.

The abstraction level is high, making it difficult for non-professionals to interpret the map. The underlying concepts of high and lows values are understood more easily, but the transformation of point features to a density surface requires more advanced knowledge of methods and might introduce a substantial amount of skepticism on the part of lay users.

Another problem encountered is the loss of the underlying information about the park visitors present during a specific snapshot. This could be solved by displaying the space appropriation simultaneously with the point data used for that snapshot (for issues of symbolization, see sections above). However, the simultaneous display of dot symbols to represent the parks visitors present clearly leads to a visually overwhelming representation of park use. Instead, it would be a suitable visualization to display the park visitors only when the animation is paused.

7.4 Global Analysis

The properties of the observational data preclude the use of some methods introduced in Chapter 5:

The use of the K-function is dependent on each singular situation observed in the parks. Therefore, it cannot be used for temporally aggregated data. On the other hand, if the K-function would be applied for each activity type for each temporal state in each park, the problem of a small sample size would arise. For this reason, the K-function was not calculated.

The Nearest Neighbor Hierarchical Clustering Index (NNHI) has the challenge of critical but user defined-parameters: Threshold distance and minimum cluster size. Levine (2006) gives impressive examples of the variance introduced through slightly different variable values. Since no rules-of-thumb or inductively gained values are yet known for the observational data, a great deal of uncertainty would be introduced with this analysis method. The results would have to be tested thoroughly for robustness. For these reasons, the application of the NNHI was postponed.

Finally, the Knox Index would have to be calculated for every observation session in order to check for temporal clustering/segregation of certain attributes (e.g. gender). Otherwise, the observation schedule and different park locations introduce an artificial clustering effect. The resulting large number of datasets and the manual processing (again no programming interface was available) precludes the use of the Knox index here.

7.4.1 *Statistical Tests for Processes of Exclusion*

The data was normalized to a hypothetical visitor count and neighborhood population of 100 each (i.e. effectively using percentages). This was for two reasons: One, to make the data more easily comparable. Two, in order to avoid a problem of the Chi-Square-Test with high population values. Since the values are squared during the calculation, small differences between observed and expected values have a strong impact at high numbers and lead to low confidence levels for falsely rejecting the null hypothesis. The first two tables (7-11 and 7-12) below show the difference between using the actual values and normalized values, while the remaining Tables 7-13 to 7-15 all use normalized values:

Table 7-11: Wahlenpark 2005 Chi-Square Test with actual values

	Male	Female	p Gender	Children	Adults	Seniors	p Age
Observed	1091	1350	< 0.00	1259	1182	0	< 0.00
Expected	1207	1233		341	1747	352	

Source: the author

Table 7-12: Wahlenpark 2005 Chi-Square Test with normalized values

	Male	Female	p Gender	Children	Adults	Seniors	p Age
Observed	44.69	55.31	0.34	51.58	48.42	0	< 0.00
Expected	49.45	50.55		13.98	71.59	14.43	

Source: the author

Table 7-13: Wahlenpark 2006 Chi-Square Test

	Male	Female	p Gender	Children	Adults	Seniors	p Age
Observed	57.85	42.15	0.09	40.76	57.35	1.89	< 0.00
Expected	49.45	50.55		13.99	71.59	14.43	

Source: the author

Table 7-14: Bäckeranlage 2007 Chi-Square Test

	Male	Female	p Gender	Children	Adults	Seniors	p Age
Observed	50.37	49.63	0.17	16.00	79.91	4.09	< 0.01
Expected	57.13	42.87		8.54	83.62	7.84	

Source: the author

Table 7-15: Savera-Areal 2007 Chi-Square Test

	Male	Female	p Gender	Children	Adults	Seniors	p Age
Observed	51.4	48.6	0.62	17.9	76.1	5.95	< 0.00
Expected	53.9	46.1		16.1	61.9	22	

Source: the author

The data shows that with regard to the age structure, the sample population in the parks is significantly different from that of the surrounding neighborhood. One can reject the null hypothesis within a confidence level of less than 0.01 in all cases.

The frequency of the gender distribution is nowhere significantly different in the sample population from the surrounding neighborhood at the standard confidence level of 0.05. It depends on the judgment of an analyst, whether a higher confidence level (such as 0.1 or even 0.2) would be acceptable.

7.4.2 *Mean Centers and Standard Deviational Ellipses*

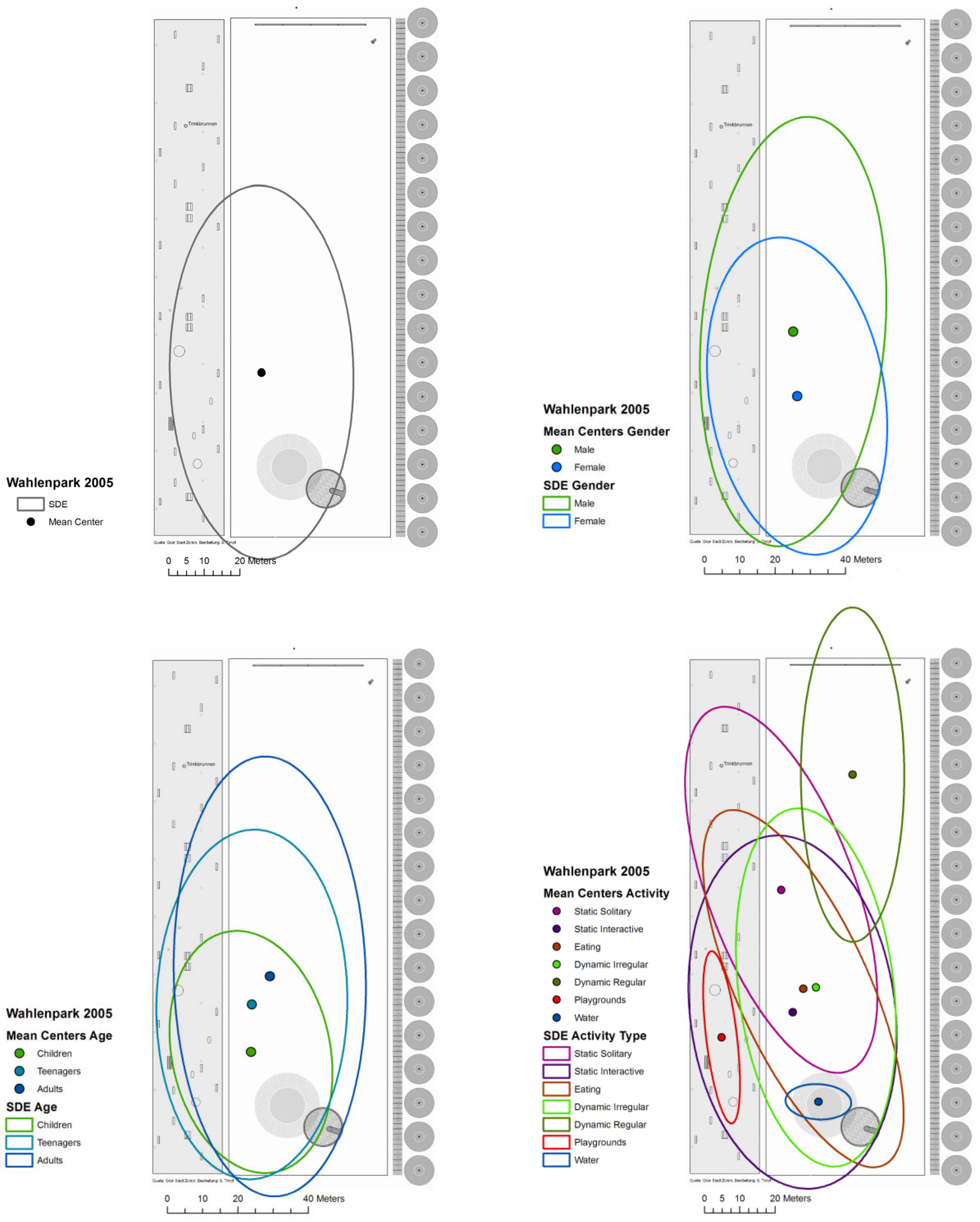
For each aggregated observation season, both spatial statistics were calculated for all features. In order to depict the two statistics, dot maps and proportional symbols are adequate. The following general remarks apply to the Figures 7-12 to 7-15:

In the case of the mean centers, the same conditions as for the exploratory visualizations apply. The variables to be mapped are all unipolar, with gender and activity type nominally and age group ordinally scaled. The same symbolizations are used to the same effect. There is no problem with occlusion of points by other mean centers, since there are only a few to be mapped.

The standard deviational ellipses, if combined on a single visualization for the sake of easy comparison, are represented best as linear features, so that they do not occlude each other. The visual variables of size, shape, and orientation are used to display the length and direction of the standard distance, while using the same hues as in the dot maps increases the familiarity with and cohesiveness of the visualizations and thereby facilitates understanding. Therefore, multivariate visualizations of gender/age, for example, are not feasible. Instead, small multiples of the SDEs are more promising, since they allow an easy comparison of location of the computed spatial statistics.

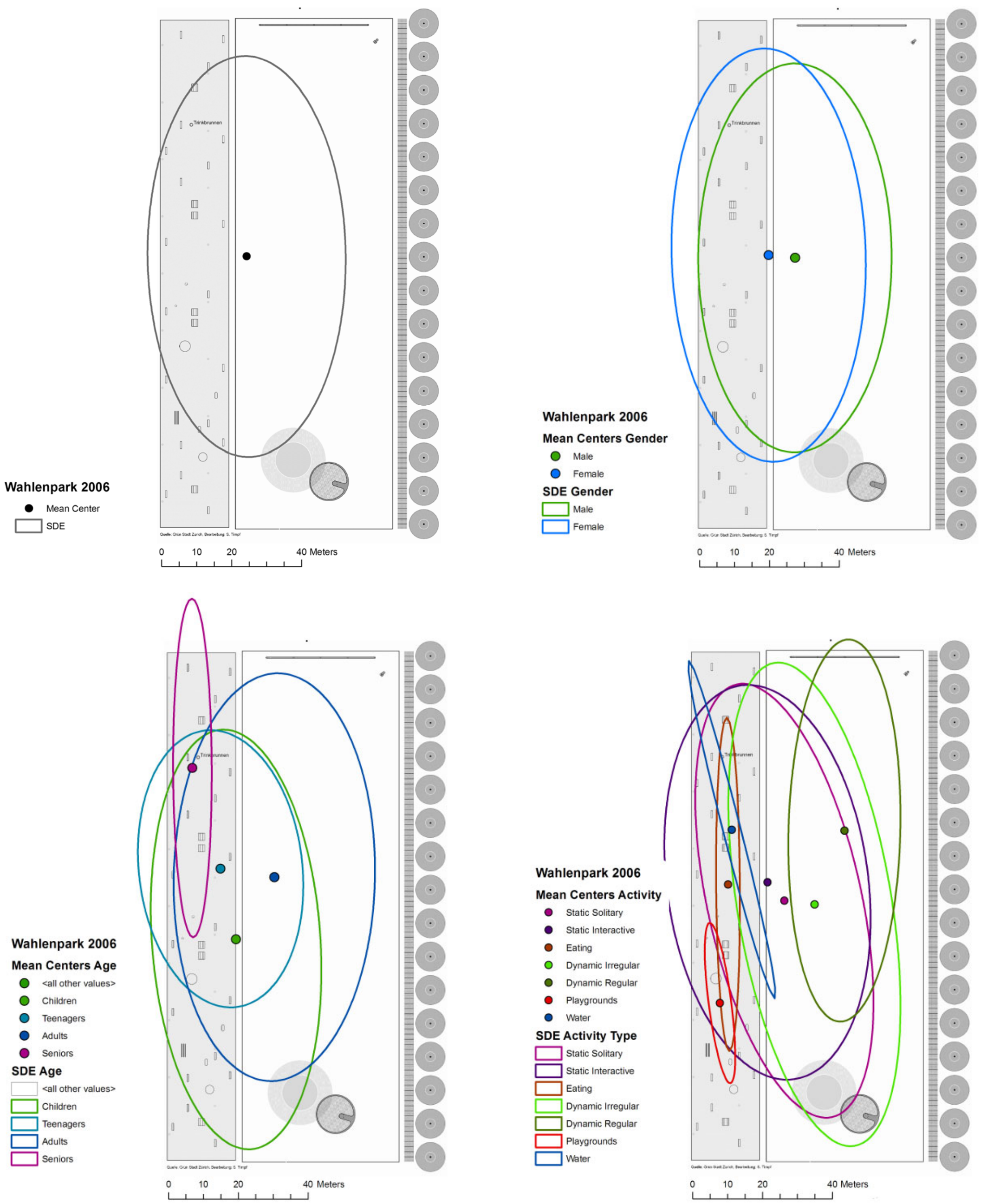
Concerning the Wahlenpark (Figure 7-12 and Figure 7-13)**,** the genders seem to have a slightly different spatial distribution. The trend observed in the dot maps during the exploratory analysis is confirmed: The male visitors use more of the open space than the female visitors do, because their mean center and SDE are nearer to the open area than the females'. Concerning the age groups, the children are closer to the water, while the adults seem to prefer the open spaces. This pattern for age follows a clear trend: The older, the more extended into the open area, excepting the Senior age group. The main difference between the years 2005 and 2006 is that in 2006 there was no water for most of the observation sessions. While in 2005 the visitors are clustered around the lower end of the area where the basin is, in 2006 the mean centers and SDEs are more centrally located. In addition, in 2005 no seniors at all were observed. The activities that require infrastructure are localized accordingly. Dynamic regular activities (like football) are located farther away at the northern end of the park. In 2006, when there was no water in the pool, most activities have shifted towards the western strip with benches and tables, except dynamic activities that remain on the open grassy area.

Figure 7-12: Mean Center and SDE Wahlenpark 2005



Source: own design

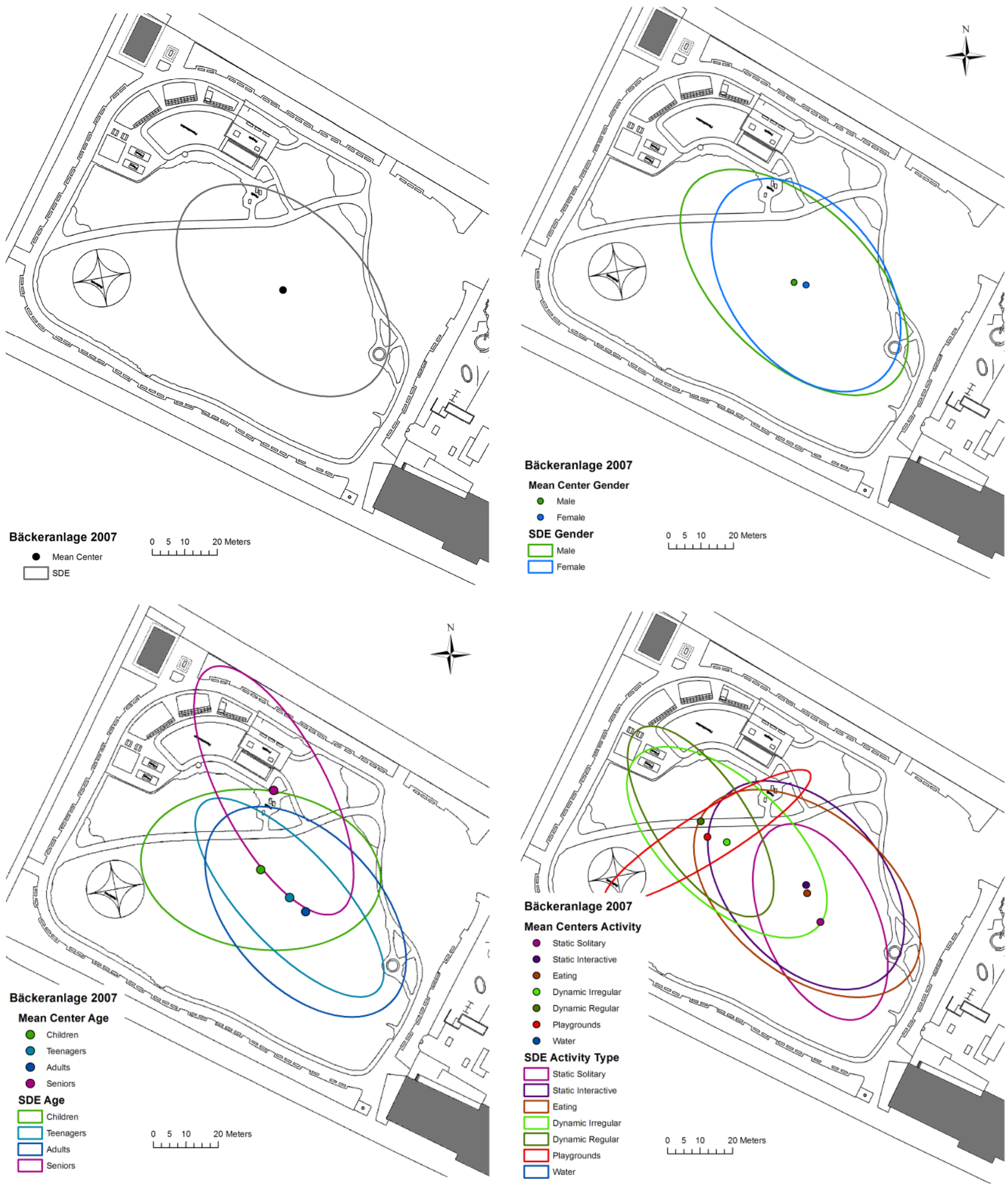
Figure 7-13: Mean Center and SDE Wahlenpark 2006



Source: own design

In the Bäckeranlage (Figure 7-14), the less structured design makes the kind of statements similar to those about the Wahlenpark more difficult and prone to error. It is obvious though, that again seniors prefer benches and tables, children the water, and adults the open spaces. No significant difference between genders seems discernable. The SDE for playgrounds is directed orthogonally to the other SDEs, with the statues and climbing structure at both ends. The dynamic activities are rather in the northwestern area, while static solitary are located in the southeastern corner.

Figure 7-14: Mean Center and SDE Bäckeranlage 2007



Source: own design

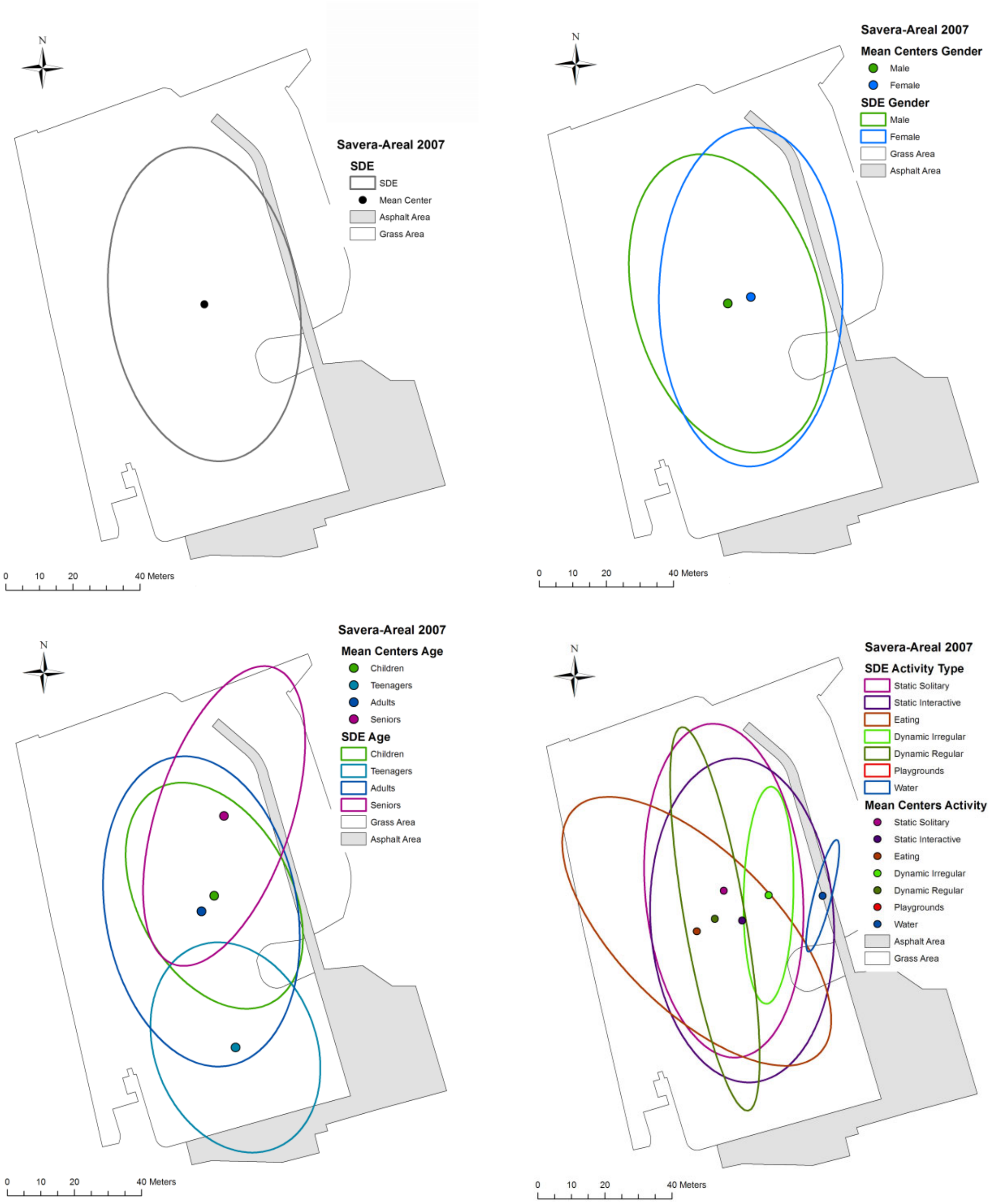
In the Savera-Areal (Figure 7-15), the senior visitors do not have many benches to sit upon, but concentrate at the quieter northern end. The teenagers clearly cluster in the southern end, while the children are again closer to the water, and adults are shifted towards open space. As in the Wahlenpark, there seems to be a correlation between female SDEs and children's SDE (both are closer to the water than the rest). Since children do only have limited influence on the gendered SDEs (about 17% of visitors are children), this could be attributed to female visitors attending to the children. The elongated SDEs for dynamic activities hint at the fact that most took place at both ends of the park, while the other activities are more centered.

In theory, one could also compute the mean center and SDE for each moment of the observed time. The nature of the data precludes this, since there are periods when only a very limited number of visitors were present in the parks. It is not advisable to calculate the measures of mean center and SDE with such small samples, because outliers could distort the result severely and not be representative.

7.4.3 *Nearest Neighbor Index*

The nearest neighbor index has only limited analytical value in this research context. One can expect a clustering of activities and other attributes (due to the visitors groups). More interesting is where those clusters are located. A temporally aggregated calculation (i.e. per observation season) is only valid for comparing certain intra-attribute or inter-location clustering, i.e. whether male or females are more clustered, or whether activities in one park are more clustered than in others. This is due to the fact of different group sizes that influence the clustering and the index. However, any reasoning based on such an analysis is problematic because I assume that the distribution in space is highly situational. Hence, one could only reasonably calculate the index for each temporal state of the park. Then, however, the number of simultaneous events/visitors is much lower, and if tested for too many separate classes, some results will not be based on a sufficiently large sample. The attribute of gender is the only one that seems appropriate for this analysis. A comparison of nearest neighbor indices for all parks based on gender (Table 7-16) shows that in the Wahlenpark, females are more clustered than males, while in the Savera-Areal the males are slightly more clustered. All results show the expected outcome of highly significant clustering.

Figure 7-15: Mean Center and SDE Savera Areal 2007



Source: own design

Table 7-16: Nearest Neighbor Indices

Park Season	Nearest Neighbor Index Males	Significance level	Nearest Neighbor Index Females	Significance level
Wahlenpark 2005	0.69	< 0.01	0.63	< 0.01
Wahlenpark 2006	0.6	< 0.01	0.55	< 0.01
Bäckeranlage 2007	0.64	< 0.01	0.6	< 0.01
Savera-Areal 2007	0.67	< 0.01	0.76	< 0.01

Source: the author

7.4.4 *Kernel Density Estimates*

An observation effect and observer bias might distort the analysis results to a certain degree. During the measurement (i.e. the observations), the observers placed a new dot (event) when there was a significant, permanent relocation of activities. This means that park visitors who are involved in static activities but relocate these activities several times (such as moving with the shadow of a tree, for example) are weighted more than those who stay in the same place for hours, or those who move around a lot but do not change the center of their activities. In addition, there is an observer bias introduced, because it is left to the observer's judgment when a notable relocation has taken place. Although extensive training of the observers should have minimized this effect, its influence might still be significant. To account for this in a static aggregated result, there are two basic strategies: The time kernel method and adjusted population values. The time kernel method has been developed by Katajisto and Moilanen (2006). Very often in ecology research, the data gathered has a non-regular spatial and temporal granularity. Some observations are in close succession, while others are several days apart. For the delimitation of a habitat, kernel density estimates based on these observations suffer from the same unintended weighting as this project's data. With the time kernel method, observations are weighted based on their spatial and temporal proximity: The closer they are together, the less weight they receive. The second option, the population parameter, weighs the points (events) based on an attribute value, which could be the duration of the activity at that location. In this way, all visitors are weighted according to their time spent in the park. Adjusting the population values seems sufficient and was employed in this analysis.

For each observation season, kernel density estimations were performed for all visitors grouped for gender and activities. A relative density of gender was calculated by subtracting the values of male density from those of female density, resulting in map showing the relative "surplus" of each gender. The activities were grouped into general static ones (Static Solitary and Interactive, Eating) and general dynamic activities (Dynamic Irregular and Regular, Playgrounds, and Water). As the preceding analysis has shown, some age groups are represented by very small samples, and additionally the age groups have a predisposition towards certain types of activities. For this reason, I do not intend to pursue the hypothesis for age groups, and the density for them is not shown in the following visualizations (Figures 7-16 to 7-23).

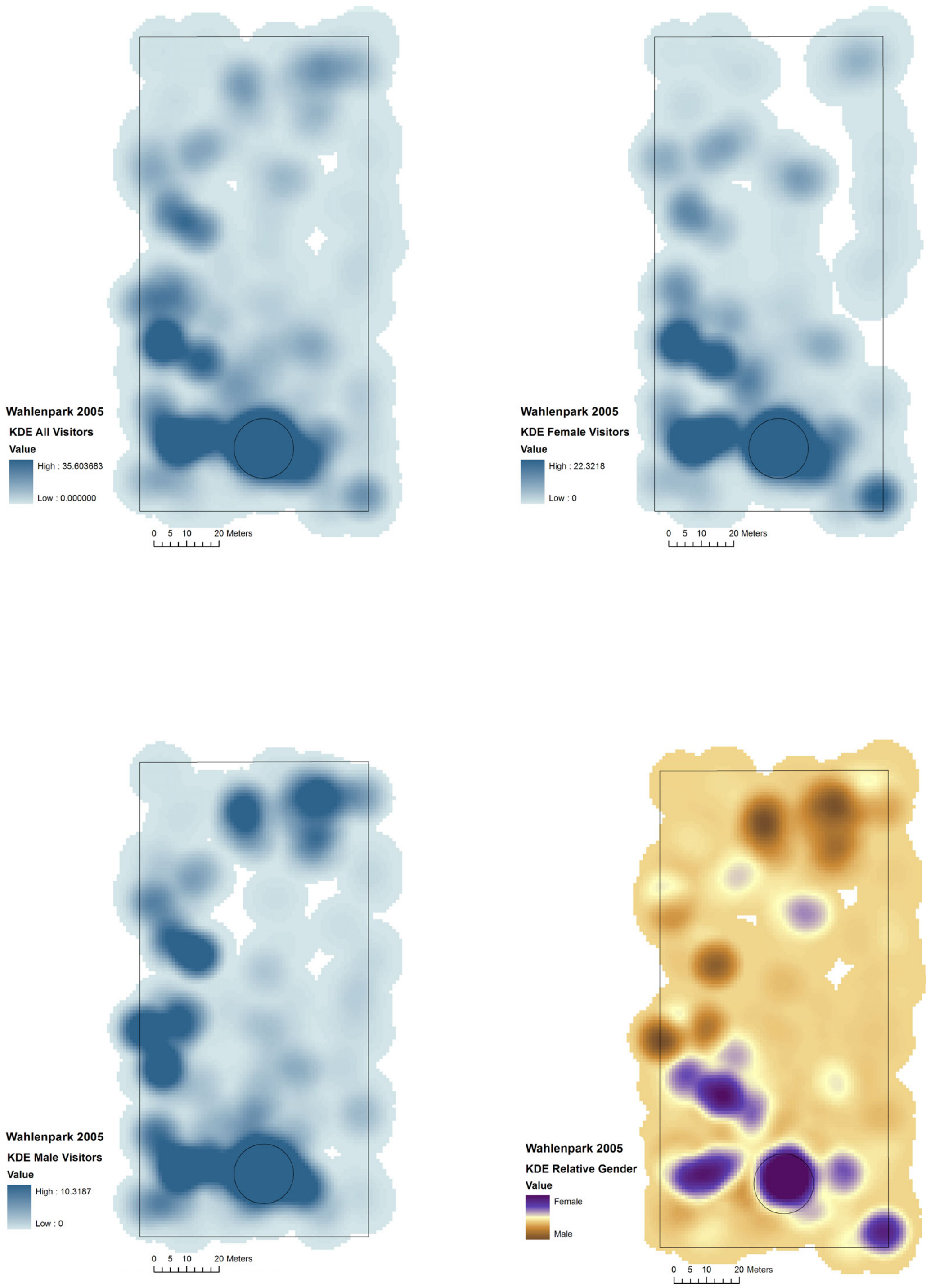
The parameters were as follows: Cell size was one meter, output units were square meters, population was the calculated duration, and search radius 10 meters. As with the results of the field-based computation, the density results are shown in isarhithmic representations. Note that the absolute values differ significantly. They are dimensionless but listed to enable comparisons. Using the same minimum and maximum values for the unclassified symbolization would have facilitated comparison, at the expanse of then not discernable details. The stretch parameter is two standard deviations, i.e. all values greater than two standard deviations are mapped with the maximum color value. This reflects the fact that the maximum absolute value is only meaningful in comparison to other maxima, and is dependent on the number of observation hours: The longer the observations, the more activity would have been observed, and the higher this value would be. Therefore, this stretch parameter results in the impression of a higher activity density. However, this reflects a valid extrapolation of the representative data and smoothes outliers that might be the result of a single observation session. The relative density of male versus female visitors is displayed using a bipolar color scheme.

The level of complexity is high, and the interaction is reduced to changes in the symbology once the values have been computed.

Starting with Figure 7-16 for the Wahlenpark in 2005, the maximum density of female visitors is more than double that of the male visitors (approx. 22 vs. approx. 10). It is the highest around the water basin and southern playgrounds. Male visitors concentrate in the regions, but also use more of the open space, especially the northernmost part that is designed for ball games.

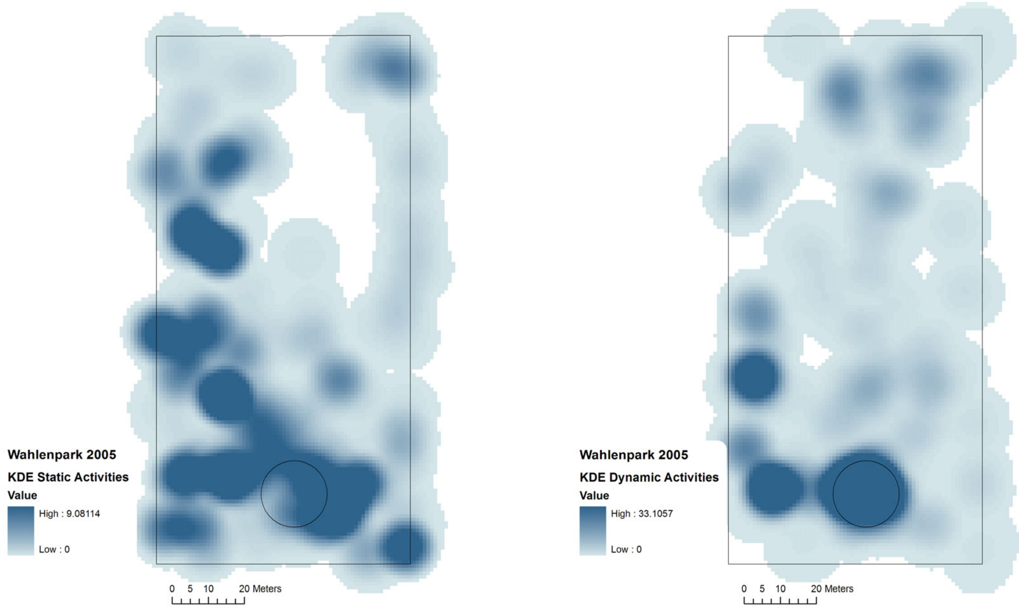
Concerning the activities (Figure 7-17), the dynamic activities generally have a much lower density (approx. 9) than static activities (approx. 33). The water basin in the southern half is an attractor for all types of activities. While children prefer dynamic activities, running around and in the water, the attending adults rather watch and talk. The open grass area is used almost exclusively for dynamic activities, while the same is true for the northwestern part for static activities.

Figure 7-16: KDE Wahlenpark 2005 Gender



Source: own design

Figure 7-17: KDE Wahlenpark 2005 Activity Type

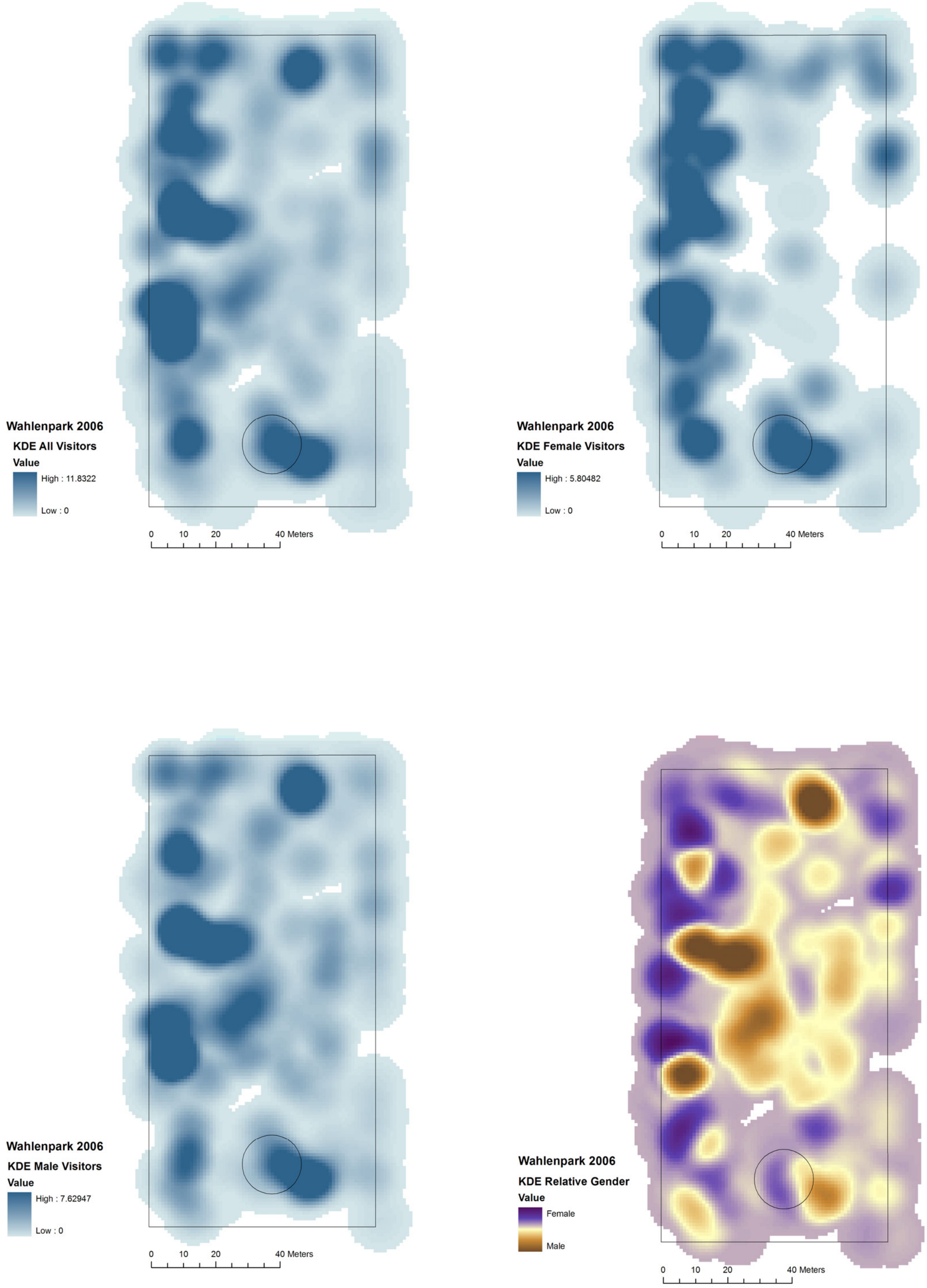


Source: own design

In the year 2006 (Figure 7-18), the open grass area is again used less than the western and southern part. However, at the same time the extensive space use on the grass area originates almost exclusively from male visitors, while the female visitors concentrate in the remaining parts of the Wahlenpark.

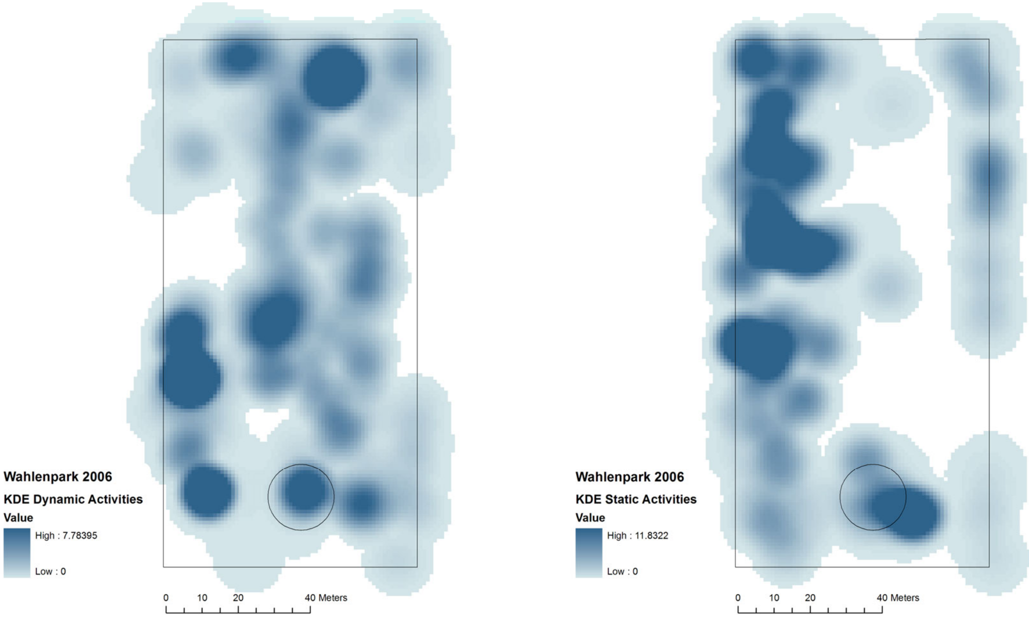
The infrastructure obviously has again a large effect on the type of activity (Figure 7-19). In the southwestern area where the playgrounds are located, as well as on the open grass area, dynamic activities dominate the space use. In the shaded area southeast of the basin and the northwestern part with tables and benches, static activities dominate. The missing water in the basin leads to that area being much less in use than in the year before.

Figure 7-18: KDE Wahlenpark 2006 Gender



Source: own design

Figure 7-19: KDE Wahlenpark 2006 Activity Type

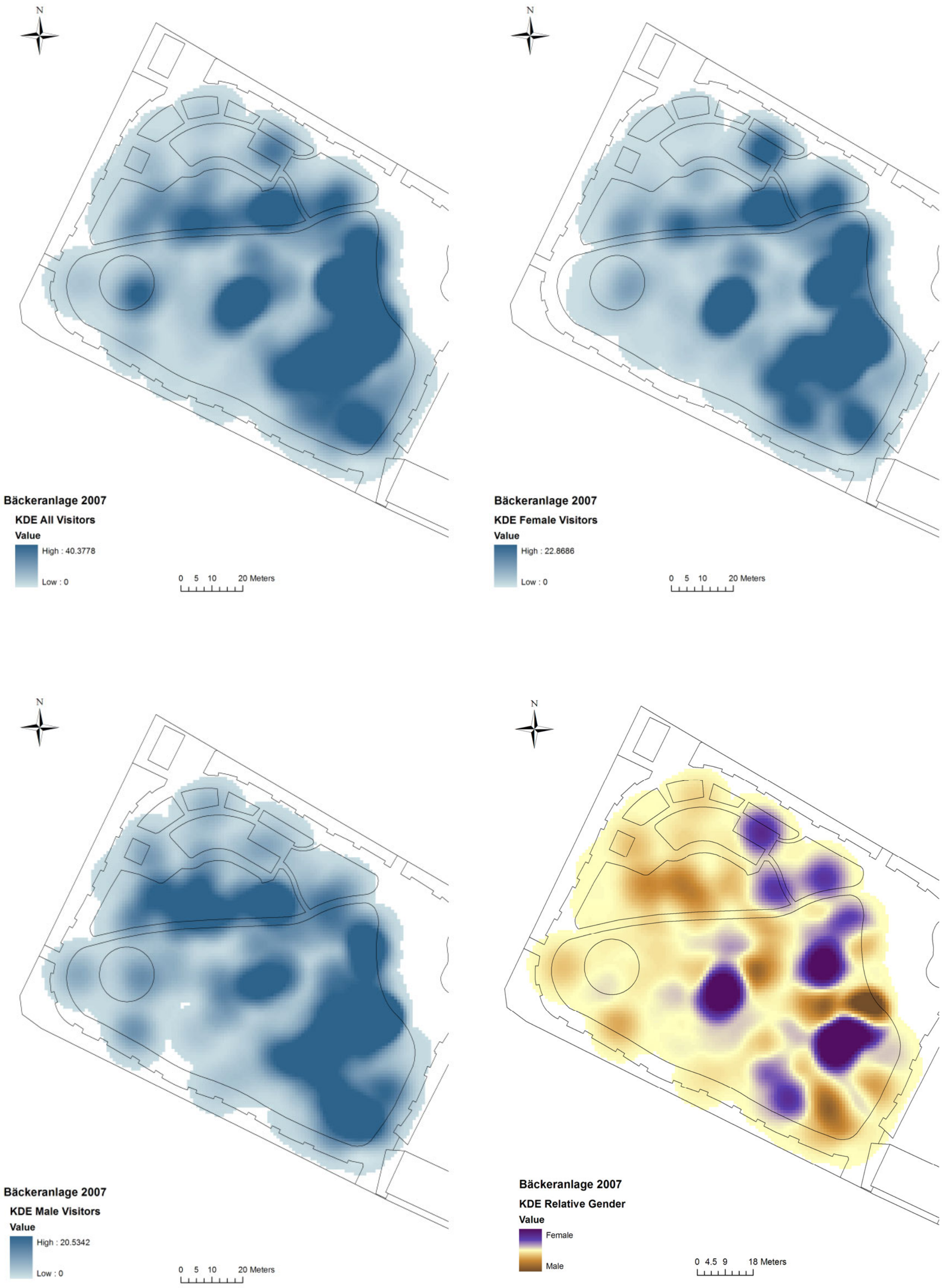


Source: own design

In the Bäckeranlage (Figure 7-20), the absolute density of male and female visitors is similar (20.5 and 22.9, respectively). Both genders use the eastern and central part. However, female visitors dominate the area around the large tree, while the smaller grass area seems dominated by male visitors.

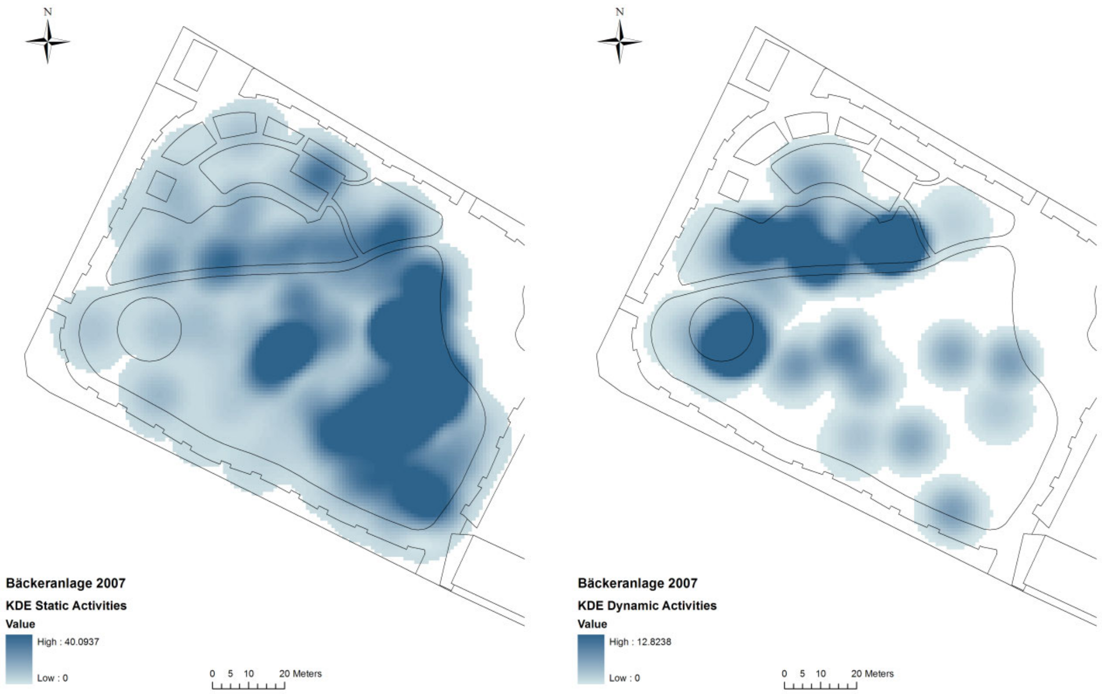
The static and dynamic activities (Figure 7-21) are unevenly distributed over the area. There is a separation between quiet but intensive space use in the eastern part, and a more active but extensively used western part (compare the absolute values of approx. 40 for static activities and 12.8 for dynamic activities). The southeastern part is surrounded by low hedges and is used mostly for the solitary activities of reading or sleeping. The large central open area is dominated by a hot spot corresponding with a large tree that provides shade. The dynamic activities concentrate on the playgrounds and the smaller grass area, where mostly ball games are played.

Figure 7-20: KDE Bäckeranlage 2007 Gender



Source: own design

Figure 7-21: KDE Bäckeranlage 2007 Activity Type

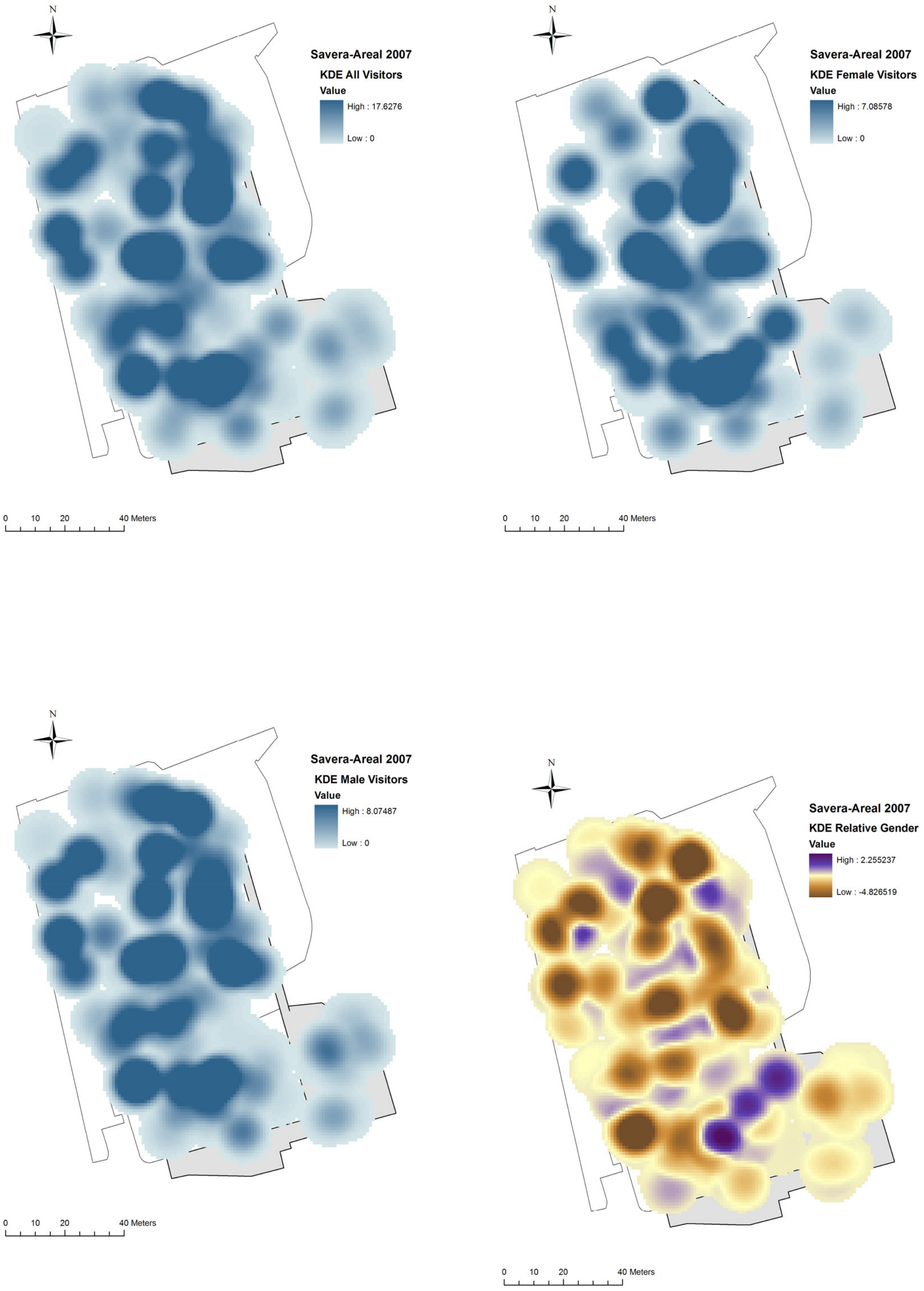


Source: own design

In the Savera-Areal (Figure 7-22), the absolute densities of male and female visitors are comparable. At the same time, the maximum density is lower than in the Bäckeranlage. The density of female visitors is higher towards the lakeshore to the east, while male visitors seem to be located more towards the western areas of the park. The whole area is more or less evenly used.

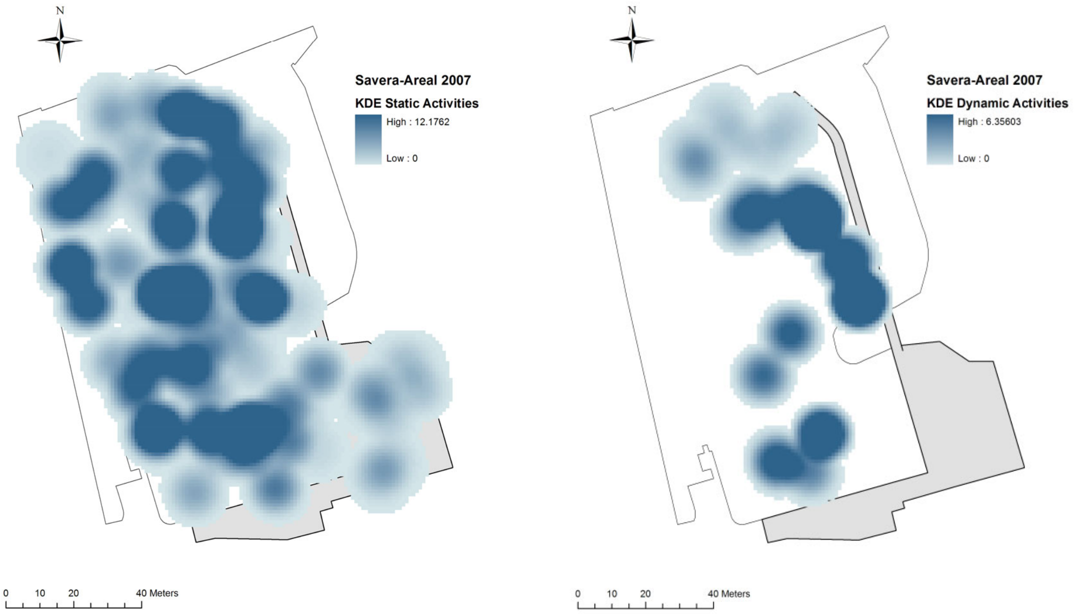
The dynamic activities (Figure 7-23) are located rather at the periphery or towards the lakeshore, while the static activities dominate the central open grass area. This affirms the impression of the exploratory analysis.

Figure 7-22: KDE Savera-Areal 2007 Gender



Source: own design

Figure 7-23: KDE Savera-Areal 2007 Activities



Source: own design

7.5 Interpretative Synthesis

The hypotheses on spatio-temporal clustering (see section 7.1.4, hypotheses 3-5) could not be tested with quantitative statistical methods because of too small sample sizes available at each snapshot. Instead, I adopted a qualitative visual analysis approach for the aggregated visualizations. This section synthesizes the preliminary results from the exploratory analysis (7.1), and the results from the quantitative analysis of the previous sections (7.4):

1. Difference in the gender structure between observed sample and neighborhood population: The analysis has shown that in no observation season, the differences were statistically significant at the confidence interval of 0.05.
2. Difference in age structure between observed sample and neighborhood population: The analysis has shown that in all observation seasons, the differences are highly significant at a confidence interval smaller than 0.01.
3. Spatio-temporal clustering of males or females: The spatial analysis has shown that there is a distinctive clustering of gender in the Wahlenpark and the Bäcke-

ranlage. The male visitors occupy more of the open spaces than the female visitors, who tend to stay closer to benches, water basin, or shaded areas. In the Savera-Areal, there does not seem to exist such a difference in the location of female and male visitors. The Nearest Neighbor Index does not reveal any differences in clustering. However, there is also a temporal clustering of gender. In the observed parks, the male visitors had a significantly higher proportion during the late afternoon and early evening hours. While this only reflects the general trend in the Wahlenpark, it is reinforced with a higher proportion of female visitors in the Bäckeranlage and Savera-Areal during the midday and early afternoon.

4. Spatio-temporal clustering of age groups: I have not included a detailed spatial analysis of the age groups. Because of the small number of teenagers and seniors, and the interdependency of age group and activity type, the exploratory dot maps and KDEs for activity type enable to infer the following statements: Children use and rely upon the park infrastructure for their activities (playgrounds and water). Seniors, in contrast, rely on benches and tables. Adults most frequently communicate, eat or play ball games, all of which they prefer to do on the open spaces. There seems to be no distinct temporal clustering, however, because the proportions of the age groups remain constant over the observation periods.
5. Spatio-temporal clustering of activities: It is obvious that there has to be some spatial clustering, because some activities rely on the parks infrastructure, such as playgrounds or water basins. Most activity types can be carried out on the large open spaces, so that is where the hypothesis can be tested. While in the Savera-Areal most of the static activities are evenly distributed, the dynamic activities have been observed mostly at the northern or southern end of the grass area. In the Wahlenpark, this separation is also obvious, but encouraged by the design of the park with the water basin at the lower end and a fence to catch balls at the upper end of the park. In the Bäckeranlage, it is interesting to note that the dynamic activities occur in the northwestern smaller grass area closer to the water basins. The static solitary activities, especially sleeping, reading, and sunbathing, are mostly located at the eastern end of the grass area, where hedges provide a kind of semi-enclosure. There is a clear temporal shift of activity composition. Eating decreases after 14:00, hinting at a large number of employees having their lunch in the parks. Meanwhile, dynamic activities increase, while solitary static ones also de-

crease. This may be because people meet after work, at during midday it is too hot to play physically demanding games.

The suitability of the visualization methods is best shown in form of a table. Table 7-17 sums up the evaluation of the presented visualization techniques.

7.6 Summary of Chapter 7

The two approaches to modeling human space appropriation have shown that a discrete approach based on buffers around the event locations does not represent the nature of human space appropriation in an adequate manner. While the continuous approach has its shortcomings, it accomplishes the key requirements for the model implementation. Even with a relatively simple implementation based on kernel density estimations, a satisfying representation is possible. Problematic is the large number of necessary computations due to the situational character of space appropriation. For the analysis of the observational data, the analysis has been on the aggregated level of observation seasons for the same reason. Nevertheless, the interesting results include the following findings:

- Male visitors show more dynamic activity patterns than female visitors, although on a generally low level. The dynamic activities tend to occur in the periphery.
- The open areas tend to be dominated by the most common activity type, static interactive. The interactions occur only within groups, with almost no interaction between groups of visitors.
- Park infrastructure in general is an attractor for the younger and older park visitors, although highly differentiated between age groups. Water and playgrounds mostly attract children, while benches and tables attract seniors.
- Gender structure was not significantly different from the expected structure based on the neighborhood population. There was, however, a trend showing a decrease in female and younger visitors during the late afternoon and early evening.
- The age structure is significantly different from the neighborhood population, mainly due to lower numbers of senior visitors. Whether this is an inter-site displacement process or caused by other factors could not be determined by observations alone.

- Although spatial clusters of age groups and gender could be detected, they do not indicate general intra-site displacement processes.

While the Bäckeranlage and Savera-Areal display institutionalized use patterns, the Wahlenpark has high fluctuations in several visitor attributes.

Concerning the visualizations, static small multiples of aggregated data is well suited for the exploratory phase, while static small multiples of disaggregate data is best used for comparing specific moments or details. Overall, the dynamic visualizations are not well suited for exploration or analysis, since they are either cognitively overwhelming with too much detail, or a large number (one for each observation session) has to be generated, analyzed, interpreted and compared to the others. The same applies to visualizations using the third dimension for depicting time. The discrete dot and continuous isarithmic maps provide the highest interactivity and best representation. However, there is a tradeoff between the lower level of abstraction of the discrete dot maps and their reduced analytic value, or the higher level of abstraction of the continuous isarithmic maps and their suitability for visual analysis.

Table 7-17: Summary of Visualization Evaluation

		Interactivity	Small Multiples	Realism, Complexity	Function and Target Audience
Discrete 2D dot and isopleth maps	static	high (easy manipulation of symbology and querying)	facilitate comparison of snapshots or variables	low realism, but easy to interpret	explorative, suited for practitioners and researchers
	dynamic	medium (easy manipulation of symbology, very basic animation controls)	cognitively very challenging,	increased realism, still easy to interpret	explorative, suited for practitioners and researchers
Discrete 2D choropleth maps	static	low (no on-the-fly calculation)	facilitate comparison snapshots or variables	low realism, but easy to interpret	explorative, hindered by low interactivity
	dynamic	low (no on-the-fly calculation)	cognitively very challenging	increased realism, still easy to interpret	explorative, hindered by low interactivity
Discrete 3D dot maps	static	potentially high	cognitively challenging	high level of abstraction and complexity	explorative, geared towards researchers
	dynamic	not applicable, because temporal dimension visualized through third display dimension			
Continuous 2D isarithmic maps	static	very low (no on-the-fly calculation, limited manipulation of symbology)	facilitate comparison between snapshots and variable interactions	most adequate representation, but high level of abstraction	analytic (cluster etc.), probably geared towards researchers
	dynamic	very low (no on-the-fly calculation, limited manipulation of symbology)	cognitively very challenging,	best representation, but high level of abstraction	analytic (cluster etc.), probably geared towards researchers
Continuous 3D isarithmic maps	static	very low (no on-the-fly calculation, limited manipulation of symbology)	cognitively challenging, increased by very low interactivity	adequate representation, but high level of abstraction	explorative for researchers, (visual) analysis
	dynamic	very low (no on-the-fly calculation, limited manipulation of symbology)	cognitively very challenging,	adequate representation, but high level of abstraction	analytic (cluster etc.), probably geared towards researchers

Source: The author

PART V: DISCUSSION & CONCLUSIONS

8 Discussions

In this Chapter, I will first discuss the model of space appropriation developed in Chapter 4, before I discuss the analysis results and visualizations from Chapter 7.

8.1 Quantitative Model of Space Appropriation

8.1.1 *General Remarks*

In the fourth Chapter, I developed a model of human space appropriation that allows a quantification and subsequent analysis with spatial analysis methods. Two principal components were identified that determine human spatial behavior at the micro-scale: The desire of park visitors for enough privacy to carry out their intended activities (represented by their personal spaces), and the competition of other visitors endeavoring the same (represented by their activity footprints). Based on the relevant literature, I argue that in the sphere of urban public parks, these two components are sufficient to represent human space appropriation adequately. As I have already argued in Chapter 2, the other control mechanisms rarely play an important role: Establishment of a territory in an ephemeral environment as a park is not as important as elsewhere, and park visitors seem to acknowledge that any claim to a territory is a weak one. The project team also rarely observed verbal and non-verbal communication between different groups. Its frequency might increase if there is almost no space left, but even under circumstances of high density as were observed in the Bäckeranlage, verbal interchange was very rare. In this context, it is important to remember that high visitor density is not automatically a negative factor (Altman 1975; Freedman 1975). There is no evidence to date that it introduces a higher level of stress or discomfort. The effect of high visitor density is situational and individual: It reinforces already existing feelings of discomfort or of joy. One can assume that part of the reason to visit a park is to be in the presence of others, even if no interaction is occurring. The motivation is to have fun and relax, therefore an underlying positive mental state can be assumed. An unexpected encounter or interaction could be felt as enrichment of the experience than an actual disturbance. This seems to be true even for potentially very disturbing activities such as BBQ, music or football.

Another important point to keep in mind when discussing the model, is the fact that it cannot explain the motivation why someone visits a park. That motivation can also explain to a great part the reaction a park visitor shows when confronted with some disturbance. For that reason, the project team combines empirical work and qualitative methods in this research.

8.1.2 *Object-based Implementation*

The object-based implementation of the model of space appropriation is straightforward, since buffering is one of the core spatial analysis methods and implemented in a wide range of software products. The computation runs fast enough, and the few parameters are in standard spatial dimensions and adjustable. This makes the concept easily understandable and usable by a wide range of practitioners. An object-based spatial analysis has some advantages: The buffering is not restricted to circular buffers, and future methods should enable specific forms of activity footprints and personal distance zones. The advantage of an object-based representation is that additional information can be stored in the attributes of the polygons, e.g. contributors, time, etc. The temporal attribute of discrete objects enables queries that are more refined, and more advanced analysis, including temporal topologies. Therefore, I propose to continue work on the object-based representation and combine it with field-based representation for analytical purposes.

The main drawback of using discrete buffers is the non-discrete nature of human space usage and appropriation. The intensity of space usage and appropriation decreases continuously but non-linearly with the distance from the individual person. The crisp boundaries of buffers can lead to sharp jumps in space usage intensity and in resulting potential crowding and conflict. It would be possible to approximate the decreasing intensity of space appropriation by using more buffer ring intervals, at the expanse of computing time. Still, the output does not resemble how humans appropriate space. Additionally, the crispness of object-based analysis conveys the notion that the computation and the results are absolute and non-ambiguous. The very nature of human space appropriation is quite the opposite of this, with vague boundaries of human personal spaces and activity footprints and some yet uncertain parameter values. A continuous distance function can provide a solution here, so that there are no sharp discontinuities in both space appropriation and conflict potentials, suggesting crisp boundaries where there are actually none.

8.1.3 *Field-based Implementation*

The problems of object-based representations of human space appropriation are solved to a great degree by a field-based continuous representation. The vague nature of human spatial behavior is emphasized by research literature from environmental psychology and related disciplines, and is supported by empirical evidence. A continuous field representation of human space appropriation captures the vague boundaries best. The non-linear distance decay and additive effect of multiple contributors to space usage is well represented by kernel density estimates. The parameters for the estimations are few and can be adjusted easily.

At the same time, these parameters are the biggest obstacle to a useful application of the model, because there is not (yet) enough empirical evidence to provide theoretically sound parameter values for different categories of park users and activities. Bandwidth is the principal parameter besides population, and at the moment its value is chosen arbitrarily. One has to keep in mind that this arbitrariness is no problem in absolute terms, since there is no unit of human space usage or appropriation and kernel density estimates have no meaningful units. Nevertheless, the relative values for different activities have to be chosen carefully. One can only compare different realizations with observed reality. Therefore, the flexibility of the approach remains to be tested. The temporal dimension is included from the beginning, but an interactive modification of parameters with on-the-fly calculation and visualization needs significant processing power (response times are too slow for on-the-fly interactivity), and data redundancy is high. Acknowledging these problems, there are no other, more suitable field-based approaches.

The KDE function for calculating space appropriation from point data is still too inflexible, as it should allow asymmetric kernel functions. Other commercially available products offer slightly different options. However, for a full application of the model, functions that allow asymmetric rotatable kernel densities, i.e. different bandwidths on the x- and y-axis and the possibility to rotate these, still have to be implemented. The algorithms used allow much room for improved efficiency and optimization, so that reduced response times increase the interactivity.

The temporal dimension has not been part of the analysis yet, because of the inherent constraints of a field-based representation. In addition, a multi-variate grid representation would be advantageous. For example, values representing uncertainty or probability could be visualized from this data simultaneously with information about space appropriation.

Some of the shortcomings of the field-based representations could be ameliorated with a combined discrete/continuous representation that retains and displays additional information. Once interesting patterns are discerned using point pattern visualization and analysis, the corresponding space appropriation could be calculated and visualized on the fly. Increases in computing power as well as optimized code will support and enable such solutions.

8.1.4 *Uncertainty in the Model*

The boundaries of the personal distance zones have been proved relatively consistent throughout all reviewed studies. Uncertainty is introduced by the fact that individual attributes like gender, ethnicity, and personal experience and interests can modify the overt behavior when interaction moves into inappropriate distance zones. This fact could be represented by additional modifiers to the personal distance zone used for determining the level of desired privacy. The activity type already acts as a modifier and is considered the most important factor, but other parameters like gender, ethnicity and motivation can be incorporated. Before doing so, more empirical evidence is necessary on the precise effects these attributes have on the preferred interaction distances.

The activity footprints also introduce uncertainty, since there is little or no information on the space that typical activities occupy. It is unclear, whether a sufficiently accurate yet simple typology is possible at all. Individual modifiers to these footprints have not been determined yet – one might expect a group of males drinking alcohol have a different effect on the surrounding area than a family with children picnicking, although both would fall under the “Static Interactive” and “Eating” activity types in the observations. This uncertainty can be reduced, however, by feeding the analysis results back into future model implementation.

8.1.5 *Uncertainty in the Computation*

The two computational models employed treat the uncertainty very differently: The object-based model allows the easiest modification of parameters. All the individual differences in preferred personal distance zones and activity footprints can be incorporated with ease into the computation of both space appropriation and potential crowding, as has been shown. More problematic is the implementation of the vague boundaries and resulting inaccuracy in values. The nature of the object-based computation allows only for a very limited amount of vagueness that either has to be introduced in the form of even more shapes (and associated problems) or additional attributes of the shapes. In the latter case, the uncertainty has to be quantified in order to make standardized measurements possible. This approach seems not very promising, mainly because it introduces new types of uncertainty.

The field-based model implementation uses a normal distribution as base function for the computation. This kernel function is not only reflecting the intensity of space use, but also a probabilistic representation of the likelihood that the state at that particular location is true. Consider again the case of a reader and a football player: The location of the reader is well known, relatively exact (about one meter) and mostly static. The activity footprint is small. Therefore, the kernel density uses a small bandwidth, resulting in higher, sharper peak. Both the intensity of space use and the likelihood that the reader is at that particular location are highest at the center of the distribution (the original data point). A football player has a much larger activity footprint. For that reason, a larger bandwidth was used. The resulting density surface spreads out more than the activity footprint of the reader, but is also lower at its center. This reflects both the lower intensity of space use at a particular location, and the reduced likelihood of being at that location because of the dynamic nature of playing football. If the researcher assumes that different activity types have specific and different amounts of space usage intensity, this can be reflected in the computation by choosing specific population values associated with activity types (or other variables such as gender or ethnicity). Although this reflects the variation of uncertainty more appropriately than the object-based representation, the problem of the choice for parameter values (especially bandwidth) persists. Since the intensity of space use is dimensionless, the absolute values for bandwidth and population only have to be in correct relation to each other.

8.2 Discussion of the Analysis Results

8.2.1 *Representation and Representativity*

In this thesis, the implementation of storing spatio-temporal data was based on the concepts and rules of the available geodatabases. Experience so far has shown that simply extending a spatial data model to include temporal data will result in inflexible and inefficient representations for spatio-temporal data. Nonetheless, the capabilities of the employed software were a constraint that forced to rely on time-stamping and snapshot models of representation. The amount of work that proved necessary to make the data readable by the multitude of stand-alone software solutions showed the urgency that an advanced logical model for spatio-temporal data gains widespread use and acceptance. The simple dichotomy of raster and vector datasets should be replaced with a combined model that is open-source and can be implemented by a wide range of applications. While a replacement for the snapshot model might be difficult to implement for field-based data (the very concept implies that there is always a state for each location), object-based data should be handled as such, with space and time as attributes of the entities.

The nature of the observations and the resources at hand clearly indicate that representative results cannot to be expected at all temporal granularities. At the level of specific days of the week, the sample would be too small, because a maximum of 14 sessions per park and season was planned. However, at the level of observations seasons, the data is sufficiently representative for a statistical analysis. The same is true for the spatial distribution of visitors. The number of observed visitors and activities is large enough to claim representativity. The average distance observed between group members and others could thus be used as a measure for retuning and recalibrating the model parameters. Concerning the representation of activities, it is likely that the impact of dynamic activities on the park usage and appropriation might be underestimated or underrepresented. Although several measures (including weighing by duration of stay and disaggregate analysis) counter the effect of the observation method’s bias towards static activities, activities involving constant movement in a larger area might be inadequately represented.

8.2.2 *Spatio-Temporal Analysis of Recorded Data*

The analysis of the original discrete point data is possible with established spatial analysis methods. Bearing the limited representativity in mind (see previous section), this allows for reliable testing and analysis with a low uncertainty involved. Mean centers, SDEs, nearest neighbor index and kernel density estimates are relatively straightforward.

The temporal analysis had to remain a primarily qualitative visual one. The complex nature of human spatial usage, appropriation, and interaction makes a data mining approach to detect hidden causes and effects very challenging. A pattern could be returned because of user-introduced bias instead of an actual case of domination and exclusion. One would have to augment the data with the motivation of the park users, so that one could determine why an observed reaction like relocation has occurred. In order to detect any temporal cycles in park usage, many more observations would be necessary, and it would be in effect a comparison of distributions with spatial analysis methods.

Another restriction is that the observations could not take into account the effects of nearby infrastructure such as the community center in the Savera-Areal, the school near the Wahlenpark or the community center in the Bäckeranlage.

The results presented in Chapter 7 support some of the views encountered in the literature, while refuting others. Comparing the data and the results with a study from the city of Basel (Baur, Zemp et al. 2000), many similarities exist:

- The highest visitor density is around the infrastructure, e.g. playgrounds or water, as well as in shaded or more secluded open spaces.
- The highest number of visitors is between 14 and 20 o'clock.
- Adults are the most numerous group, followed by children. Seniors only infrequently visit parks.
- The most frequent activity type is static activities like observing, communication, or reading, followed by infrastructure and dynamic activities.
- The most heterogeneous areas are in the peripheral open areas and around playgrounds. This is where the highest conflict potential can be assumed. The large open spaces show a clear segregation of activities.

While parks are clearly an important location for families with children, there were also many younger visitors ranging from 20 to 30 years of age. During the day, mostly mothers oversee the children while fathers usually are present with the mothers and children only later during the day. The teenager age group is underrepresented. There is not only a spatial but also a temporal segregation of activities in small parks. The results show that the dynamic activities increase their share during the late afternoon and early evening hours. While during the day the park visitors rather pursue solitary activities for relaxation, eat lunch, or attend children, during the later hours ball games and static interactive activities dominate. It is obvious that the type of infrastructure provided also channels the activities. Water is a focal point for children, as are playgrounds. Trees or other structures providing shade are also sought-after, as are areas that can serve as a vantage point.

However, some analysis results differ from those reported in the literature. Concerning a potential domination of the open spaces by space-consuming, dynamic male activities (Oertzen von 2002; Paravicini 2002), the results showed no indication of such domination. To the contrary, the dynamic activities were located at the periphery of the open spaces in all parks, while the center was dominated by quiet static activities.

Our empirical results do not support a hypothesis that systematic processes of exclusion and displacement are at work. The only group of visitors that was actively turned away were squatters: Male visitors drinking beer throughout the day were spatially marginalized but present. The analysis results show that a heterogeneous population of visitors uses the parks for diverse activities. The statistical tests showed that the age structure is significantly different from the neighborhood's age structure for all parks. A comparison of the two reveals that seniors are underrepresented, as are children in the Bäckeranlage and the Savera-Areal. The former have limited mobility and therefore need more infrastructure than some parks might provide, while the latter probably gather at different locations. Seniors citizens might also tend to stay at home during the hot weather when the observations took place. Statistical tests also showed that the difference in gender structure between park samples and neighborhood population is not highly significant. However, in this case the author presumes that committing type II errors (falsely not rejecting the null-hypothesis) is more dangerous than committing to a type I error (falsely rejecting the null hypothesis), and the standard confidence level of 0.05 is too low. At a confidence level of 0.10, male visitors are significantly overrepresented in the Wahlenpark, while at a confidence level of 0.20, male visitors would be underrepresented significantly in the Bäckeranlage.

8.2.3 *Uncertainty in the Recorded Data*

Since the main concern of the research is the development of a model and analysis methodology, no additional effort was undertaken to reduce the inherent inaccuracy and imprecision. As argued in section 6.4.3, one can consider the quality of the raw data as adequate for the representation of human space use and appropriation in public parks. Improvements to the data capture technique could include video observations, although this could introduce ethical issues of privacy and control of personal data. The need for the development of an automated digitization technique would also arise, although some advanced methods of automated movement tracking exist. Another solution would be agent-based modeling, where these types of uncertainty do not exist (but others are introduced).

8.3 Discussion of the Visualizations

8.3.1 *Visualization Technique and Target User Group*

For the visualizations produced in the thesis, I used established cartographic guidelines that describe suitable symbologies for certain types of data. It seems that the needs of practitioners and researchers are quite different. A practitioner might not be concerned as much with the actual analysis as a researcher. More important are overviews that show where specific problems might exist. Either these problems can then be addressed through additional empirical work, such as traditional interviews, or through direct action such as changing the design and layout of parks and comparing the actual results to the intended results. If this trial-and-error method is not suitable, then simple spatial analysis such as a computation of maximum number of simultaneous park visitors based on personal spaces and activity footprints is sufficient. Different layouts can be tested for a maximization of simultaneously usable park space. To this end, the dot maps and a simple overview density map are sufficient. A 2.5D surface showing the density or intensity as height can enhance the communication via double encoding, but is not necessary. If a high level of interaction is desired, 2.5D visualizations can actually be counterproductive, because of their reduced interactivity.

Researchers on the other hand are interested in more detailed, multi-variate visualizations. Here, a 3D visualization like the space-time cube can provide additional insight, if possible with a high level of interaction. Using the third dimension for visualizing the temporal dimension increases the usefulness of perspective height as visual variable. The space-time cube used in the first phase of the exploration gave no information on the amount of time visitors stayed and used the park. It would be possible to extrude the feature according to their duration. However, such a visualization will be even more visually overwhelming and cluttered than the original space-time cubes. Space appropriation could be approximated by extending the radius, thereby creating volumes of space. This concept is known in time geography as space-time-prism or – if plotted on a surface – potential path areas. The intensity of space use could be visualized using lightness. The resulting visualization might be very complicated and not be intuitively understandable or showing patterns. The large number of prisms will most certainly lead to occlusion. A high interaction that allows on-the-fly manipulation of viewer perspective, zooming and filtering is a prime requisite for the effective use of this visualization method.

The density surfaces can be shown as small multiples for a large number of snapshots and/or variables, offering the best basis for visual comparisons (Griffin, MacEachren et al. 2006). Additional animations could show a level of detail depending on the speed of the animation, so that the rate of change does not exceed human perceptual and cognitive capabilities. When the animation is stopped, additional detail such as overlaid dot maps can provide more information on the situation at that moment in time. For a close-up inspection of large-scale (spatial and temporal) data, the space-time cube is an additional promising method. However, a volumetric, true 3D display of space appropriation places high demands on hardware, software and interaction design.

8.3.2 *Uncertainty in the Visualizations*

In Chapter 3, possible techniques for the visualization of uncertainty have been presented and discussed. In general, uncertainty can be either visualized using intrinsic methods or extrinsic methods. The latter depends on additional symbology such as glyphs or other objects, the former on the use of visual variables. In our case, the uncertainty is very difficult to quantify, i.e. there is no measurable error by which observed or calculated values differ from a real-world value. Because of this, extrinsic visualizations are difficult to realize. It is important to keep in mind that an accurate depiction of uncertainty still fails in its purpose if the disseminated information is easily misinterpreted. The uncertainty of object-based computations is almost impossible to judge and thereby convey. In the case of kernel density estimates, the uncertainty is already inherent in the derived values and therefore needs no special visualization. A different approach would be to calculate several runs of the model with varying parameter values and compare the results. This can be done either by visual comparison by simultaneously or alternating depicting the realizations, or by subtracting one from the other and displaying the difference. If so desired, this difference in values (the variance in values for every location) could be visualized together with a single realization by employing visual variables. As suggested by the literature (MacEachren, Robinson et al. 2005), color value is the most promising, but would interfere with the visualization of actual values if a single color scheme is used (i.e. values were depicted using lightness). Saturation would be also a good candidate, while resolution can be mistaken for homogeneity of values. Crispness is not appropriate for field-based data, and transparency difficult to implement and interpret in this specific case.

9 Conclusions

In this final chapter of the thesis, I revisit the key research objectives and questions that I posed in the introductory Chapter 1, and attempt to answer them concisely. In the end, new questions wait for further research.

9.1 The Research Questions Revisited

For the reader's convenience, I restate the main research questions from Chapter 1:

1. What model could represent the spatio-temporal properties of space appropriation and potential crowding?
2. Which methods are suitable for modeling space appropriation, analyzing the observation data, and visualizing the results?
3. What is the spatio-temporal distribution of observed park visitors, and do the resulting patterns of space appropriation indicate processes of exclusion and domination?

9.1.1 *Modeling Human Space Appropriation*

Concerning the first research question, I propose a model based on individual park visitors and the attributes of location, time, activity type, gender and age. Underlying assumption is that the presence of people and their activities produce space, but at the same time are also influenced by space. This reciprocal relationship can be conceptualized as the attempts of people to achieve a desired level of privacy for carrying out their intended activities. The main individual control mechanism for the regulation of the achieved privacy is the maintenance of adequate interpersonal distances. If the achieved privacy is more than the desired privacy, the individual may experience feelings of isolation. If on the other hand the achieved privacy is less than the desired privacy, the individual may experience crowding. The phenomenon of crowding is highly subjective and simple density does not represent it adequately. The crowding may become so intense that occurrences of stimulus overload and social interference manifest. Possible coping mechanisms include reduced interaction and displacement, which reduce social sustainability.

Human space appropriation has therefore two components, which represent the space actively used, and the space claimed by everyone as personal. In the model I developed, they are termed activity footprints and personal spaces, respectively. Together they enable a representation of the interaction between individuals in their attempts to achieve a desired level of privacy. The size, shape and direction of the activity footprints and personal spaces depend on the variables of activity, gender, age and ethnicity, and the facing of a visitor. To begin with, the model focuses on the most important variable of activity type, which was determined by the literature review.

An overlap of one individual's activity footprint with another individual's personal space could represent a potential for crowding, stimulus overload, and finally conflict. The intersection of personal spaces and activity footprints is a simple and elegant method to analyze whether the presence of individuals and their activities potentially conflict. It is important to remember that this potential for conflict does not indicate that an actual conflict or even dissatisfaction emerges. A crowded situation reinforces mostly existing states of mind. Therefore, if someone is looking for a communal feeling, then a lack of potential stimuli is also a lack of potential interaction, and thereby could enhance negative feelings of isolation.

9.1.2 *Methods for Implementing the Model, Analysis, and Visualization*

The model was implemented with both discrete object-based and continuous field-based methods, using buffers and kernel density estimates respectively.

The implementation of the object-based approach is based on buffers around the event locations. However, it does not represent the nature of human space appropriation in an adequate way. Its crisp boundaries of activity footprints and personal spaces and their uniform values suggest a homogeneity and clarity that does not reflect actual space appropriation. In addition, they lead to sharp and drastic jumps in computed potential crowding. The relative straightforwardness of the approach is an advantage, as are the possibility of complex shapes for activity footprints or personal spaces, and the preserved information on who contributed to which appropriation of an area.

The continuous approach in the form of fields accomplishes the two key requirements for the model implementation: First, a non-linear, smooth distance decay of space appropriation intensity. Second, it represents well the inherent uncertainty in the form of inaccuracy, incompleteness, and vagueness. Even with a relatively simple implementation based on symmetric kernel density estimations, a satisfying representation is possible. A drawback is the loss of underlying information about the park users.

The actual usage and appropriation of space can be captured with data from observations that recorded age, gender, and activities as primary components. Individual park users are recorded as points with the relevant attributes. The observations were planned systematically for three parks over the span of three years to acquire representative data. The observed parks in the case study were selected for their function in the city context as neighborhood parks, and their suitability for observations. Although pen-and-paper observations provide the greatest flexibility and the least amount of hardware, the digitization is prone to error and time-consuming. As a result, a new, digital observation method was developed, using Tablet-PCs and GIS-software for direct input of observations. It requires more preparation and instructions of the observers, but providing more flexibility and rigidity at the same time. The technology is sufficiently robust, and the team did not encounter any serious hardware or software problems. Still, the number of park visitors that can be recorded per observer is limited to about fifteen to twenty. For larger numbers, a more aggregated approach is necessary which in turn reduces the advantages of direct digitization.

The recorded data is event-based. It underwent several transformations during post-processing, such as calculation of new attributes (e.g. duration of stay), a reclassification of activities and age categories, and finally a merger of all datasets. The data is representative at a larger scale. The uncertainty introduced by the observations was acknowledged, and the quality of the data judged adequate for analysis.

The global distribution of visitors and their activities was subject to analysis with established quantitative spatial analysis methods, such as mean centers, standard deviational ellipses, and kernel density estimations. A systematic temporal analysis has not been possible in the scope of this project due to the large number of observations, which need to be analyzed individually.

Finally, the visualizations relied mostly on symbology and were evaluated using a simple framework based on the level of interactivity and complexity. For the specific purpose of visualizing and analyzing the distribution of park visitors and their activities, qualitative dots maps in conjunction with space-time-cubes provided a starting point. They also proved the easiest to query, to manipulate and to animate, thereby showing merit as a tool for practitioners. They fail, however, to represent adequately space appropriation, and suffer from the problems of cluttering and occlusion. The results of more advanced analysis of space appropriation, i.e. density distributions and surface features, can rarely be calculated on the fly. This low interactivity makes their use difficult for exploratory purposes. Additionally, they demand of the user a higher level of abstraction and some knowledge about the underlying analysis methods. Animations of both visualization approaches give a good overview, but at the same time are difficult to use for comparisons and need extensive pre-processing. Thus, they are best suited for showing exemplary cases of park use.

9.1.3 *Spatio-temporal Usage and Appropriation Patterns*

Concerning the third research question about the actual use of the observed parks, the analysis has been on the aggregated level of observation seasons (see above). The key findings from Chapter 7 are restated here:

- Male visitors show more dynamic activity patterns than female visitors, although on a generally low level.
- The dynamic activities tend to occur in the periphery.
- The most common activity type (static interactive) dominates the open areas.
- Interactions occur only within groups, with almost no interaction between groups.
- Park infrastructure in general is an attractor for the younger and older park visitors: Water and playgrounds mostly attract children, while benches and tables attract seniors; adults dominate the open spaces.
- Gender structure was not significantly different from the expected structure based on the neighborhood population.
- During the late afternoon and early evening, the number of female and young visitors decreases.
- The age structure is significantly different from the neighborhood population, mainly due to a lower number of senior visitors.
- While the Bäckeranlage and Savera-Areal display institutionalized use patterns, the Wahlenpark has high fluctuations in several visitor attributes.

Although spatial clusters of age groups and gender could be detected, they do not indicate general or persisting intra-site displacement processes. During the observations, the team has not recorded any direct processes of intra-site displacement. A debriefing with the observers showed that no one had witnessed any direct, unfriendly verbal exchanges between park users. Even potentially disturbing activities like BBQ or ball games or music never lead to the “flight” of nearby visitors. Whether the low number of senior visitors is an inter-site displacement process or caused by other factors could not be determined by observations alone.

9.2 Scientific Relevance and Implications

In this section, the proposed contributions to the scientific community are specified in more detail.

1. **The development of a new conceptual and methodological framework for the representation of human space appropriation**: Based on research in environmental psychology, a new concept and framework for the quantitative analysis of individual human space appropriation was developed. It incorporates a model for the representation of individual human spatial behavior, and the application and evaluation of several spatial analysis methods for the implementation of said model.
2. **New extensive data collection**: Under the supervision of the author, a team of observers has conducted extensive field observations in several parks over the span of three years, recording the location, age, gender, and activity of park visitors in a database. This is the first representative, detailed survey of park use that includes exact location, time and activity of the visitors.
3. **The application of existing spatial analysis techniques to a new research domain**: The new data has been analyzed with several spatial analysis and geovisualization techniques, thereby applying those to the area of individual social interaction for the first time. To knowledge of the author, there is no other research employing similar methods on human space use at the micro scale.
4. **A cross-disciplinary approach to a specific problem:** This thesis combines elements from many different disciplines and applies them to a specific problem. Its cross-disciplinary approach incorporates geographical information science, computer science, information visualization, psychology, cognitive sciences, sociology, and urban planning.

The research described has led to many interesting and potentially useful insights. Clearly, each user group seems to have certain preferences with regard to the park infrastructure. Therefore, a diverse infrastructure gives the heterogeneous user groups the possibility to participate. A clearly structured infrastructure reduces the potential for conflict, as it is more obvious which uses are encouraged where, resulting in better arguments should a dispute occur. In the interviews, visitors also reported problems with large open spaces that do not suggest any specific usage while exposing those present to a large audience. This is especially true for female visitors.

From a managerial perspective, it could therefore be advantageous to concentrate on few types of usages and discourage antagonistic types of activities. However, this depends on the intention of the planners how public open space is supposed to be used. If the priority is given to comfort and well-being, such a separation might work in the beginning. It is to be expected that if no other park can offer the discouraged activities in the vicinity, that some parts of the park are used for those purposes instead of those originally intended, thus provoking more conflict than originally planned. If public open spaces are understood as places where participation and negotiation are desirable, then a heterogeneous mix of usages should be the objective.

9.3 Outlook

There are new questions that emerged during the project.

First, several measures could improve the model on space appropriation. Among them is the implementation of the additional variables of facing, gender, age and ethnicity. Additionally, the effect of social interference (i.e. “goal-blocking”) could be modeled using overlaps of activity footprints. Before this would be feasible, the values for the employed parameters have to be verified by more observations and extensive and systematic testing of the model for robustness. The results from the qualitative analysis and in-depth interviews as empirical method will provide additional insight into the motivations of the park visitors.

The empirical method introduced in this research has proved to be effective up to a certain size of park or number of visitors. I recommend the combination of detailed observations of a few park visitors to get representative behavior, while at the same time recording aggregated measures for all park users. The large number of recorded data will need new approaches to mining it for information. In addition, the temporal dimension and the search for temporal causalities needs improved treatment. Finally, the visual representations need testing and systematic evaluation with both practitioners and analysts.

A future research objective could be the agent-based modeling of human space appropriation, so that different park layouts and infrastructures can be tested on carrying capacities, social sustainability and acceptance before they are actually built (Chang 1997; Castelfranchi 1998; Gimblett 2001; Boman and Holm 2004; Moulin, Chaker et al. 2004; Brown, Riolo et al. 2005; Cole 2005). This could also help to answer questions which strategy is more effective for a sustainable use of urban public parks: Conflict prevention through segregation or conflict management through encouragement of heterogeneity.

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APPENDIX

VBA Script: Calculate End Times and Duration

```
Attribute VB_Name = "CalculateTimes"
Option Explicit

Private pFCursor As IFeatureCursor
Private pFeature As IFeature
Private pField As IField
Private pFields As IFields
Private pFieldEdit As IFieldEdit
Private pTableSort As ITableSort
Private pDataStatistics As IDataStatistics
Private pStatResults As IStatisticsResults
Private intFieldPos1 As Integer
Private intFieldPos2 As Integer
Private intFieldPos3 As Integer
Private intFieldPos4 As Integer
Private dblMaxOID As Double
Private intCount As Integer
Private intFCount As Integer
Private intCrtOID() As Integer
Private intCrtID() As Integer
Private intNxtID() As Integer
Private lngStartTime() As Long
Private lngEndTime() As Long
Private lngDefStartTime As Long
Private lngDefEndTime As Long
Private intDuration As Double
Private intDurHours As Double
Private intDurMinutes As Double

Public Sub CalculateEndTime()

    ' prepare for editing
    Set pFields = pFClass.Fields

    ' get number of features
    intFCount = pFClass.FeatureCount(Nothing)

    ' get max OID
    Set pDataStatistics = New DataStatistics
    Set pFCursor = pFClass.Search(Nothing, False)
    Set pDataStatistics.Cursor = pFCursor
    pDataStatistics.Field = "OBJECTID"
    Set pStatResults = pDataStatistics.Statistics
    dblMaxOID = pStatResults.Maximum

    ' set array sizes
    ReDim intCrtOID(intFCount)
    ReDim intCrtID(intFCount)
    ReDim intNxtID(intFCount)
    ReDim lngStartTime(dblMaxOID)
    ReDim lngEndTime(dblMaxOID)

    ' create new TableSort, sort ascending by ID
    Set pTableSort = New TableSort
    With pTableSort
        .Fields = "ID, start_num"
        .Ascending("ID") = True
        .Ascending("start_num") = True
        Set .QueryFilter = Nothing
        Set .Table = pFClass
    End With
    pTableSort.Sort Nothing

    ' create cursor for sorted TableRows
    Set pFCursor = pTableSort.Rows
    Set pFeature = pFCursor.NextFeature

    ' set start of observation
    lngDefStartTime = InputBox("StartTime of Observations (hhmmss):")
```

```
' set end of observation
lngDefEndTime = InputBox("EndTime of Observations (hhmmss):")

' field names
intFieldPos1 = pFields.FindField("ID")
intFieldPos2 = pFields.FindField("start_num")
intFieldPos3 = pFields.FindField("end_num")
intFieldPos4 = pFields.FindField("end_str")

' initialize counter
intCount = 0

' populate EndTime with values
Do Until pFeature Is Nothing

    ' get OID of current feature
    intCrtOID(intCount) = pFeature.OID

    ' get ID of current feature
    intCrtID(intCount) = pFeature.value(intFieldPos1)

    ' get StartTime of current feature
    lngStartTime(intCount) = pFeature.value(intFieldPos2)

    ' advance to next feature
    Set pFeature = pFCursor.NextFeature

    ' needed for last feature when pFeature is now Nothing
    If pFeature Is Nothing Then

        intNxtID(intCount) = intCrtID(intCount)

        ' if last record of ID set enddate to DefEndTime
        lngEndTime(intCrtOID(intCount)) = lngDefEndTime

    Else

        ' get ID of next feature
        intNxtID(intCount) = pFeature.value(intFieldPos1)

        ' if ID of next feature is the same as current feature
        If intNxtID(intCount) = intCrtID(intCount) Then

            ' set endDate of current feature to start date of next feature
            lngEndTime(intCrtOID(intCount)) = pFeature.value(intFieldPos2)

        Else

            ' if last record of ID set enddate to DefEndTime
            lngEndTime(intCrtOID(intCount)) = lngDefEndTime

        End If

    End If

    intCount = intCount + 1

Loop

' create update cursor, make it recyclable
Set pFCursor = pFClass.Update(Nothing, True)
Set pFeature = pFCursor.NextFeature

' initialize counter
intCount = 0

' Do loop to process all features
Do Until pFeature Is Nothing

    ' get OID of current feature
    intCrtOID(intCount) = pFeature.OID

    ' populate endTime fields with values from lngEndTime
    pFeature.value(intFieldPos3) = lngEndTime(intCrtOID(intCount))
    pFeature.value(intFieldPos4) = lngEndTime(intCrtOID(intCount))
```

```
        pFCursor.UpdateFeature pFeature

        Set pFeature = pFCursor.NextFeature

        intCount = intCount + 1

    Loop

End Sub

Public Sub CalculateDuration()

    ' create update cursor, make it recyclable
    Set pFCursor = pFClass.Update(Nothing, True)
    Set pFeature = pFCursor.NextFeature

    ' field names
    intFieldPos1 = pFields.FindField("start_num")
    intFieldPos2 = pFields.FindField("end_num")
    intFieldPos3 = pFields.FindField("dur_num")

    ' initialize counter
    intCount = 0

    ' Do loop to process all features
    Do Until pFeature Is Nothing

        ' check if valid duration can be calculated
        If pFeature.value(intFieldPos1) > lngDefStartTime _
               And pFeature.value(intFieldPos2) < lngDefEndTime Then

            ' calculate potential minutes
            intDuration = CInt _
                ((pFeature.value(intFieldPos2) - _
                pFeature.value(intFieldPos1)) / 100)

            ' calculate potential hours
            intDurHours = CInt _
                (Int(pFeature.value(intFieldPos2) / 10000) - _
                Int(pFeature.value(intFieldPos1) / 10000))

            ' convert to minutes
            If intDurHours = 0 Then
                intDurMinutes = intDuration
            Else
                intDurMinutes = intDuration - (intDurHours * 40)
            End If

            pFeature.value(intFieldPos3) = intDurMinutes

        Else

            ' if not set duration to -1
            pFeature.value(intFieldPos3) = -1

        End If

        pFCursor.UpdateFeature pFeature

        Set pFeature = pFCursor.NextFeature

        intCount = intCount + 1

    Loop

End Sub
```

VBA Script: Calculate Dynamic Space Appropriation

```
Attribute VB_Name = "DynamicSpaceAppro"

Private strPath As String
Private pWSFRaster As IWorkspaceFactory
Private pRasterWS As IRasterWorkspace
Private pRasterAF(1000) As IRaster
Private pRasterPS(1000) As IRaster
Private pRasAFCur As IRaster
```

```
Private pRasAFPrev As IRaster
Private pRasAF As IRaster
Private pRasCrowTmpCur As IRaster
Private pRasCrowTmpPrev As IRaster
Private pRasCrowParCur As IRaster
Private pRasCrowParPrev As IRaster
Private pRasCrow As IRaster
Private pRasterBC As IRasterBandCollection
Private strRasterBCName As String
Private strRasterRefName As String
Private pRasterRef As IRasterDataset
Private intActType As Integer
Private intActCount As Integer
Private intGrpActType As Integer
Private intGrpActCount As Integer
Private intRadiusAF As Integer
Private intRadiusPS As Integer
Private pDensityOp As IDensityOp
Private pMathOp As IMathOp
Private pRAEnvDensity As IRasterAnalysisEnvironment
Private pRAEnvMath As IRasterAnalysisEnvironment
Private pDataStatistics As IDataStatistics
Private pFCursor As IFeatureCursor
Private pEnumVarStart As esriSystem.IEnumVariantSimple
Private pEnumVarGID As esriSystem.IEnumVariantSimple
Private pFCDescriptor As IFeatureClassDescriptor
Private pFClassSSet As ISelectionSet
Private pQueryFilter As IQueryFilter
Private strQuery As String
Private valueStart As Variant
Private valueGID As Variant
Private intCount As Integer
Private intAF As Integer
Private intPS As Integer

Option Explicit

Public Sub DynSpaceAppro()

    ' set workspace
    strPath = "E:\tmp\gis\analysis_test\savera_07_test\raster_out"
    Set pWSFRaster = New RasterWorkspaceFactory
    Set pRasterWS = pWSFRaster.OpenFromFile(strPath, 0)

    ' set reference raster for extent and cellsize
    strRasterRefName = "raster_extent"
    Set pRasterRef = pRasterWS.OpenRasterDataset(strRasterRefName)

    ' create operators
    Set pDensityOp = New RasterDensityOp
    Set pMathOp = New RasterMathOps

    ' set raster analysis environments
    Set pRAEnvDensity = pDensityOp
    pRAEnvDensity.SetCellSize esriRasterEnvValue, pRasterRef
    pRAEnvDensity.SetExtent esriRasterEnvValue, pRasterRef, pRasterRef
    Set pRAEnvMath = pMathOp
    pRAEnvMath.SetCellSize esriRasterEnvValue, pRasterRef
    pRAEnvMath.SetExtent esriRasterEnvValue, pRasterRef, pRasterRef
    Set pRAEnvMath.OutWorkspace = pRasterWS

    ' create DataStatistics objects for Unique Values
    Set pDataStatistics = New DataStatistics

    ' create feature class descriptor and selection set (non-creatable) for density ops
    Set pFCDescriptor = New FeatureClassDescriptor

    ' create queryfilter
    Set pQueryFilter = New QueryFilter

    ' get unique values from start_num
    Set pFCursor = pFClass.Search(Nothing, False)
    Set pDataStatistics.Cursor = pFCursor
    pDataStatistics.Field = "start_num"
    Set pEnumVarStart = pDataStatistics.UniqueValues

    ' set first value of starttimes
```

```
valueStart = pEnumVarStart.Next

' outer loop for start times
Do Until IsEmpty(valueStart)

    ' reset counter
    intCount = 0

    ' set query filter for starttimes
    strQuery = _
        "[start_num] <= " & valueStart & _
        " AND [end_num] > " & valueStart & _
        " AND [act_rcls_num] <> 0"
    pQueryFilter.WhereClause = strQuery

    ' get unique GID values from selected set
    Set pFCursor = pFClass.Search(pQueryFilter, False)
    Set pDataStatistics.Cursor = pFCursor
    pDataStatistics.Field = "GID"
    Set pEnumVarGID = pDataStatistics.UniqueValues

    ' set first value of GID
    valueGID = pEnumVarGID.Next

    ' first inner loop for calculating AF and PS per GID
    Do Until IsEmpty(valueGID)

        ' advance counter
        intCount = intCount + 1

        ' determine group activity
        For intActType = 1 To 7
            strQuery = _
                "[start_num] <= " & valueStart & _
                " AND [end_num] > " & valueStart & _
                " AND [GID] = " & valueGID & _
                " AND [act_rcls_num] = " & intActType
            pQueryFilter.WhereClause = strQuery
            intActCount = pFClass.FeatureCount(pQueryFilter)
            If intActCount > intGrpActCount Then
                intGrpActCount = intActCount
                intGrpActType = intActType
            End If

        Next

        ' set radii for density ops
        If intGrpActType = 1 Then
            intRadiusAF = 5
            intRadiusPS = 15
        ElseIf intGrpActType = 2 Then
            intRadiusAF = 10
            intRadiusPS = 10
        ElseIf intGrpActType = 3 Then
            intRadiusAF = 15
            intRadiusPS = 10
        ElseIf intGrpActType = 4 Then
            intRadiusAF = 15
            intRadiusPS = 5
        ElseIf intGrpActType = 5 Then
            intRadiusAF = 15
            intRadiusPS = 5
        ElseIf intGrpActType = 6 Then
            intRadiusAF = 10
            intRadiusPS = 5
        ElseIf intGrpActType = 7 Then
            intRadiusAF = 10
            intRadiusPS = 5
        End If

        ' set query filter for density ops
        strQuery = _
            "[start_num] <= " & valueStart & _
            " AND [end_num] > " & valueStart & _
            " AND [GID] = " & valueGID & _
            " AND [act_rcls_num] <> 0"
        pQueryFilter.WhereClause = strQuery
```

```
        ' set selection set and descriptor
        Set pFClassSSet = pFClass.Select(pQueryFilter, _
            esriSelectionTypeHybrid, _
            esriSelectionOptionNormal, _
            Nothing)
        pFCDescriptor.CreateFromSelectionSet pFClassSSet, Nothing, "NONE"

        ' perform DensityOp AF
        Set pRasterAF(intCount) = pDensityOp.KernelDensity(pFCDescriptor, intRadiusAF)

        ' set selection set and descriptor
        Set pFClassSSet = pFClass.Select(pQueryFilter, _
            esriSelectionTypeHybrid, _
            esriSelectionOptionNormal, _
            Nothing)
        pFCDescriptor.CreateFromSelectionSet pFClassSSet, Nothing, "NONE"

        ' perform DensityOp PS
        Set pRasterPS(intCount) = pDensityOp.KernelDensity(pFCDescriptor, intRadiusPS)

        ' next GID
        valueGID = pEnumVarGID.Next

    Loop

    ' set counters
    intAF = 1
    intPS = 1

    ' second inner loop for calculating crowding
    ' loop for actvity footprints
    For intAF = 1 To intCount

        ' loop for personal spaces
        For intPS = 1 To intCount

            ' exclude same group's AF and PS
            If intAF <> intPS Then

                ' perform MathOp for a single crowding incident
                Set pRasCrowTmpCur = pMathOp.Times(pRasterAF(intAF), pRasterPS(intPS))

                ' sum crowding incidents (special conditions for first iterations)
                If intAF = 1 And intPS = 2 Then
                    Set pRasCrowParCur = pRasCrowTmpCur
                ElseIf intPS = 1 Then
                    Set pRasCrowParCur = pRasCrowTmpCur
                Else
                    Set pRasCrowParCur = pMathOp.Plus(pRasCrowTmpCur, pRasCrowTmpPrev)
                End If

                ' store partial crowding for use in next iteration
                Set pRasCrowTmpPrev = pRasCrowParCur

            End If

        Next

        ' set pRasAFCur
        Set pRasAFCur = pRasterAF(intAF)

        ' perform MathOp for summing of activities
        If intAF = 1 Then
            Set pRasAF = pRasAFCur
        Else
            Set pRasAF = pMathOp.Plus(pRasAFCur, pRasAFPrev)
        End If

        ' perform MathOp for summing of partial crowdings
        If intAF = 1 Then
            Set pRasCrow = pRasCrowParCur
        Else
            Set pRasCrow = pMathOp.Plus(pRasCrowParCur, pRasCrowParPrev)
        End If

        ' store sum of partial activities for use in next iteration
```

```
            Set pRasAFPrev = pRasAF

            ' store sum of partial crowdings for use in next iteration
            Set pRasCrowParPrev = pRasCrow

        Next

        ' save in-memory-raster of activities
        Set pRasterBC = pRasAF
        strRasterBCName = "af_" & valueStart
        pRasterBC.SaveAs strRasterBCName, pRasterWS, "GRID"

        ' save in-memory-raster of crowdings
        Set pRasterBC = pRasCrow
        strRasterBCName = "crow_" & valueStart
        pRasterBC.SaveAs strRasterBCName, pRasterWS, "GRID"

        ' next start time
        valueStart = pEnumVarStart.Next

    Loop

End Sub
```

Python Script: Data Aggregation and Merging

```
# Import system modules
import sys, string, os, arcgisscripting

# Create the Geoprocessor object
gp = arcgisscripting.create()

# Set the workspace
gp.workspace = "D:\\home\\user\\parks_gis\\parks_analysis\\parks_analysis_scratch.mdb"

# Set the necessary product code
gp.SetProduct("ArcInfo")

# Script arguments...
inFClass = ""
inLocation = "w_zones"
inTable = "vc_template_lite"
outTable = "vc_"

inFClassList = gp.ListFeatureClasses("w*", "Point")
inFClass = inFClassList.Next()
flcount = 1

try:

    while inFClass:

        gp.Copy_management(inFClass, "tmp_fc")

        # Add gender/age fields...
        #fl = "inFLayerPrep"
        fl = str(flcount)
        gp.MakeFeatureLayer("tmp_fc", fl)
        fieldlist = ["M_C", "M_A", "M_S", "F_C", "F_A", "F_S", "U"]
        for x in fieldlist:
            gp.AddField(fl, x, "SHORT", "", "", "", "", "NULLABLE", "NON_REQUIRED", "")

        # Populate new gender/age fields
        rows = gp.UpdateCursor(fl)
        row = rows.Next()
        date_str = row.GetValue("date_str")
        print date_str
        day_num = row.GetValue("day_num")
        print day_num
        slot_num = row.GetValue("slot_num")
        print slot_num
        while row:
            if row.gender == 1:
                if row.age_rcls_num == 1:
                    row.M_C = 1
                if row.age_rcls_num == 2:
                    row.M_C = 1
```

```
            if row.age_rcls_num == 3:
                row.M_A = 1
            if row.age_rcls_num == 4:
                row.M_S = 1
        if row.gender == 2:
            if row.age_rcls_num == 1:
                row.F_C = 1
            if row.age_rcls_num == 2:
                row.F_C = 1
            if row.age_rcls_num == 3:
                row.F_A = 1
            if row.age_rcls_num == 4:
                row.F_S = 1
        if row.gender == 0:
                row.U = 1
        rows.UpdateRow(row)
        row = rows.Next()

    # Calculate snapshot times
    gp.AddField(fl, "snapshot", "LONG", "", "", "", "", "NULLABLE", "NON_REQUIRED",
"")
    snapshothours = range(11, 21)
    snapshotminutes = [0, 1500, 3000, 4500]
    for x in snapshothours:
        for y in snapshotminutes:
            snapshottime = (x * 10000) + y
            print snapshottime
              expression = "[start_num] <= " + str(snapshottime) + " AND _
                  [end_num] >= " + str(snapshottime)
            gp.SelectLayerByAttribute(fl, "NEW_SELECTION", expression)
            rows = gp.UpdateCursor(fl)
            row = rows.Next()
            while row:
                row.snapshot = snapshottime
                rows.UpdateRow(row)
                row = rows.Next()
            outfc = "tmp_fc_" + str(snapshottime)
            gp.CopyFeatures(fl, outfc)

    # Merge snapshots
    fclist = gp.ListFeatureClasses("tmp_fc_*", "Point")
    fc = fclist.Next()
    vt = gp.CreateObject("ValueTable")
    while fc:
        vt.AddRow(fc)
        fc = fclist.Next()
    outfc = "tmp_merged_fc"
    gp.Merge(vt, outfc)
    print outfc

    # Identity...
    fc = outfc
    outfc = "tmp_id_fc"
    gp.Identity_analysis(fc, inLocation, outfc, "ALL", "", "NO_RELATIONSHIPS")
    print outfc

    # Summary Statistics...
    fc = outfc
    rows = gp.SearchCursor(fc)
    row = rows.Next()
    uniqueList = []
    while row:
        locValue = row.GetValue("LOC")
        if locValue <> 0:
                if locValue not in uniqueList:
                    uniqueList.append(locValue)
        row = rows.Next()
    uniqueList.sort()
    print uniqueList
    flcount = flcount + 1
    #fl = "inLayerStat"
    fl = str(flcount)
    gp.MakeFeatureLayer(fc, fl)
     summaryStats = "M_C sum; M_A sum; M_S sum; F_C sum; F_A sum; F_S sum; U sum"
    for x in uniqueList:
        expression = "[LOC] = " + str(x)
        print expression
```

```
            gp.SelectLayerByAttribute(fl, "NEW_SELECTION", expression)
            st = fc + "_" + str(x)
            gp.Statistics_analysis(fl, st, summaryStats, "snapshot")
            gp.AddField(st, "LOC", "SHORT", "", "", "", "", "NULLABLE", "NON_REQUIRED",
"")
            gp.AddField(st, "date_str", "TEXT", "", "", "", "", "NULLABLE",
"NON_REQUIRED", "")
            gp.AddField(st, "day_num", "SHORT", "", "", "", "", "NULLABLE",
"NON_REQUIRED", "")
            gp.AddField(st, "slot_num", "SHORT", "", "", "", "", "NULLABLE",
"NON_REQUIRED", "")
            rows = gp.UpdateCursor(st)
            row = rows.Next()
            while row:
                row.LOC = x
                row.date_str = date_str
                row.day_num = day_num
                row.slot_num = slot_num
                rows.UpdateRow(row)
                row = rows.Next()

        # Merge SummaryStats with template aggregated Table
        stlist = gp.ListTables("tmp_id_fc_*")
        st = stlist.Next()
        vt = gp.CreateObject("ValueTable")
        while st:
            vt.AddRow(st)
            st = stlist.Next()
        outst = "tmp_vc"
        gp.Merge(vt, outst)
        print outst
        outTable = "vc_" + inFClass
        fieldlist = ["M_C", "M_A", "M_S", "F_C", "F_A", "F_S", "U"]
        fieldmappings = gp.CreateObject("FieldMappings")
        fieldmappings.AddTable(outst)
        fieldmappings.AddTable(inTable)
        for x in fieldlist:
            fieldmap = fieldmappings.GetFieldMap(fieldmappings.FindFieldMapIndex(x))
            field = "sum_" + x
            print field
            fieldmap.AddInputField(outst, field)
            fieldmappings.ReplaceFieldMap(fieldmappings.FindFieldMapIndex(x), fieldmap)
            fieldmappings.RemoveFieldMap(fieldmappings.FindFieldMapIndex(field))
        fieldmappings.RemoveFieldMap(fieldmappings.FindFieldMapIndex("TIME_"))
        fieldmappings.RemoveFieldMap(fieldmappings.FindFieldMapIndex("FREQUENCY"))
        fieldmappings.RemoveFieldMap(fieldmappings.FindFieldMapIndex("NOTES"))
        vt = gp.CreateObject("ValueTable")
        vt.AddRow(outst)
        vt.AddRow(inTable)
        gp.Merge(vt, outTable, fieldmappings)
        print outTable

        # Clean up
        fclist2 = gp.ListFeatureClasses("tmp_*", "Point")
        fc = fclist2.Next()
        stlist2 = gp.ListTables("tmp_*")
        st = stlist2.Next()
        while fc:
            print fc
            gp.Delete_management(fc)
            fc = fclist2.Next()
        while st:
            print st
            gp.Delete_management(st)
            st = stlist2.Next()

        inFClass = inFClassList.Next()
        flcount = flcount + 1
        print flcount

except:
    gp.AddMessage(gp.GetMessages(2))
    print gp.GetMessages(2)
    if row:
        del row
    if rows:
        del rows
```